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The Vertical Jet as a Means  
Of Measuring Water

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**THE VERTICAL JET AS A MEANS  
OF MEASURING WATER**

BY

**STANLEY GARDNER CUTLER  
ROGER DEARBORN MARSDEN**

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**THESIS**

FOR THE

**DEGREE OF BACHELOR OF SCIENCE**

IN

**CIVIL ENGINEERING**

---

**COLLEGE OF ENGINEERING**

**UNIVERSITY OF ILLINOIS**

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IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

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8 in. ORIFICE ON 12 in. PIPE DISCHARGING 9 in. JET



## Contents

	Page
1 Introduction	
General conditions of Measurement. Factors in discharge formulae, Static and velocity head, Theoretical considerations for a meter	1
The Weir vs. the Vertical Jet. Disadvantages of weir. Probable error of weir and jet.	3
2 Preliminary Design.	
Authorities	5
Location and Facilities. P.T. Pipe Lines - Pump	5
Factors entering into the Design. Classification of parts. Consideration of previous tests, Final plan for apparatus	
Baffles, Discharge pipe, Measuring apparatus	7
3 Experiments with Short Tube.	
Conditions of Flow - Weir and jet - Point of transition	13
Form of discharge tube	
Preliminary Experiments. First run - Effect of lack of baffles,	14
Experiments with baffles in position. Set with 8" short tube	
Construction of tube and support, Discussion of discharge curve. Discussion of disturbance at transition. Set with 12" short tube	16
Conclusions regarding use of baffles. Cause of higher coefficient - Relative effect on high and low heads - comparison of coefficients	18
4 Experiments with Orifices.	
Considerations leading to their use. Failure of baffles to equalize flow. Suggested remedies. Disadvantage of more baffles.	



Size of baffle holes. Effect of orifice on smoothness of discharge.

Objections to orifice so used.

19

Head Measurement by Level Rods - Disadvantages of cap-

illary tubes. Objections to rods. Construction of apparatus 22

Arrangement of Apparatus. Direct pit measurement.

Methods employed - Connection for orifices

23

Results of Experiments 4" orifice on tube and reducer. 6"

orifice on tube and reducer. Wood baffles used with 12"

tube. 8" orifice with and without baffles. 10" orifice,

with and without baffles. 11" orifice with baffles

25

Discussion of Curve Form - Theory explaining form. Points

at which curve of coefficients becomes horizontal. Effect of ratio

$\frac{\text{orifice}}{\text{tube}}$  - Theoretical discussion of curve form, Generalization 29

Discussion of Equation Form - Reasons for use

31

## 5 Conclusions

In General

34

Approach pipes and connections - Considerations of head

and space. Inverted siphon - Control valve. Baffles - Reducer

34

Discharge pipes and connections - Advantages of contraction.

Disadvantages of orifice on reducer - Orifice connection - Length of tube

35

Head Measuring Apparatus. Advantages of level rods.

Telescope sight - Position of rods

37

Other Details of Design

38

Size of Apparatus. Controlling features - Relative size

of orifice and reducer - Range of various sized meters

38

Availability

40



1

# Investigation of the Vertical Jet as a Means of Measuring Water.

by R. D. Marsden, '08 and S. G. Cutler, '08.

## Introduction

General Conditions of Water Measurement. A glance at the formulae which express the quantity of water flowing thru any channel or orifice, will show that two quantities are involved: (1) The cross section area of the issuing stream, normal to the direction of flow at the point of exit and (2) the head which causes the flow. The distribution of the velocity in the cross section, while a factor in actual measurement, is not taken account of in theoretical formulae, and, in those used in practice, is taken account of by means of various empirical coefficients.

2 The first factor needs no explanation. When water is confined, the head which obtains at any point beneath its surface is called the hydrostatic head. If the water is released at that point a portion of the hydrostatic head is used in giving motion to the water, and this portion of it is known as velocity head. If the conditions still permit a certain amount of static head, this is known as pressure head, and, following the law of conservation of energy, the two latter are equal to the former. On the other hand, if the flow of water is entirely unconfined after exit, no pressure head can exist (as pressure is transmitted equally in all directions by fluids).



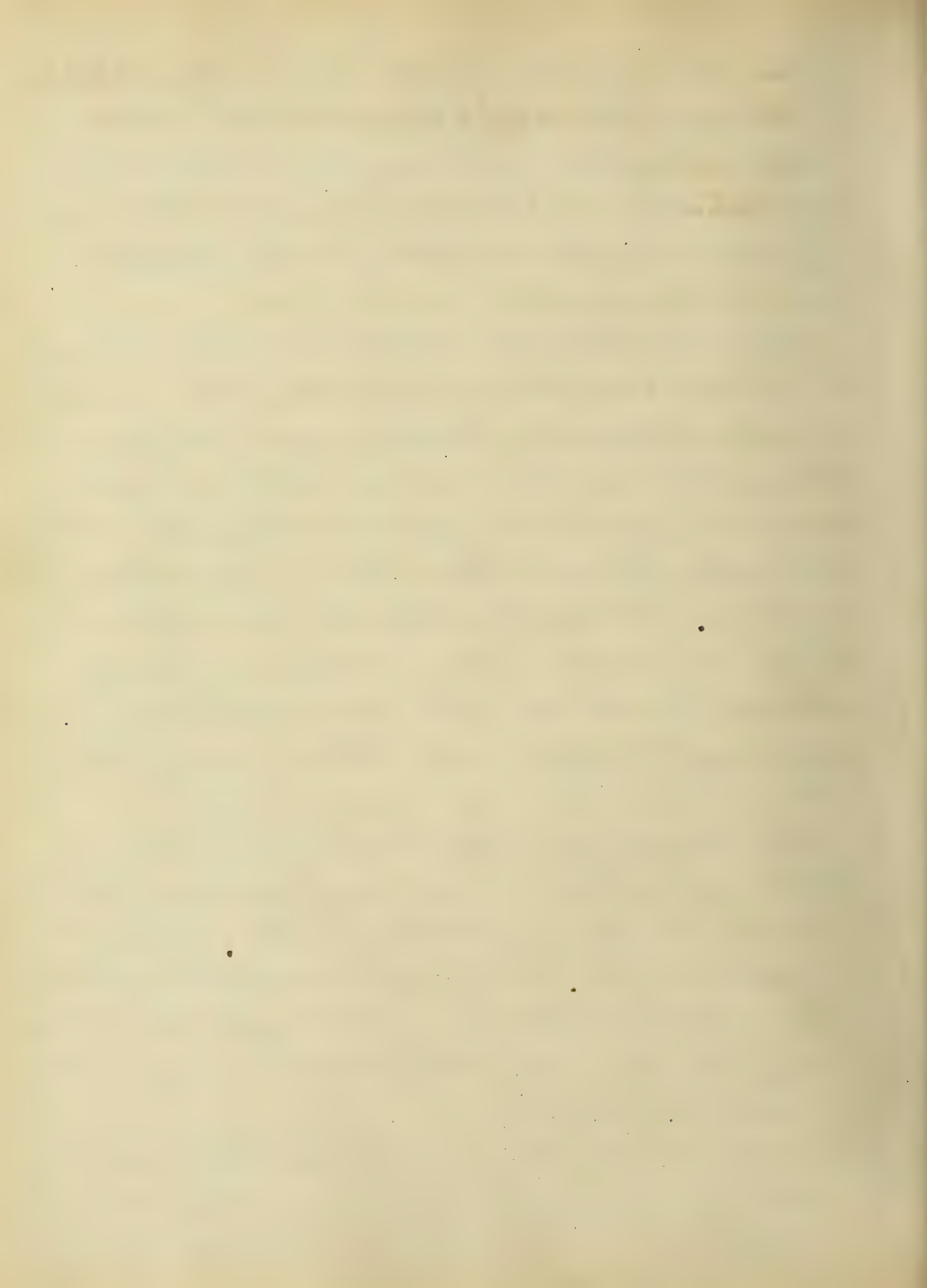
and the entire hydrostatic head must become velocity head. This is shown by the action of jets, which, when allowance is made for atmospheric friction, and for the weight of falling water on the jets, rise to the same height as the source of supply, and by the parabolic path of a horizontally projected stream from an orifice.

3 It can hardly be denied that pressure head is more easily measured than velocity head, since the latter, to be measured must be, virtually speaking, transformed again into pressure head, and friction is not a small drawback in doing this. However, it is impossible to neglect the velocity head as long as the water flows at all, altho it often becomes relatively very small, and it will be found preferable to have only one kind of head in consideration. This is not, however, a necessary consideration - only desirable. John Freeman has obtained valuable results using the nozzle, in which both pressure and velocity heads must be considered, as a measuring device.

4 From the foregoing general discussion, the following theoretical considerations for a good measuring device are stated.

(1) That either the area of the stream or the head should be constant. By means of very complicated mechanical devices, it is possible that the latter could be brought about with any apparatus, but, evidently these devices would be too impractical to consider.

(2) The area of the stream being constant, it is desirable that the head should be entirely, or very nearly pressure or velocity head. Probably the first case is most nearly brought



3

about by the small vertical orifice, and it will be shown that an horizontal orifice satisfies the second condition very perfectly.

(3) There should be as little resistance to the flow from mechanical means as possible. Friction on the sides of a channel, or atmospheric resistance, greatly impairs the result.

The Weir vs. the Vertical Jet. At the present time by far the most common method of measuring water in large quantities is by means of the weir. A weir, as used for extensive gaging, such as on river work, may be a little easier to construct in some ways than a vertical orifice of similar capacity, as the latter must have a basin properly designed to receive the flow. However, when used for exact work, this slight advantage is more than offset by the painstaking operation of bringing the weir crest to an exact level, and by the duplication of other standard conditions.

6 The weir and vertical orifice are, of course, not applicable, in ordinary practice, to conditions of submergence, while the weir cannot be used where external pressure must obtain on the water which is being discharged. In addition we must come to the conclusion, by such observations as will be considered later, that the weir is by no means an accurate meter.

7 We have, for the theoretical discharge from a rectangular weir

$$Q = \frac{2}{3} b \sqrt{2g} h^{\frac{3}{2}} \quad (1)$$



Of course, it is a well known fact in mensuration that to raise one of the observed values of any factor to a power, will increase the error of the result in an altogether disproportionate degree. If, for instance, we consider the formula for the jet, known to be,

$$Q = \sqrt{2g} H^{\frac{3}{2}} A \quad (2)$$

we have the following solution for "R", the probable error in "Q", "r" being the probable error of "h". For the weir:—

$$Q = k h^{\frac{3}{2}}$$

$$R = \left( \frac{\partial Q}{\partial h} \right) r$$

$$R' = \left( \frac{3}{2} h^{\frac{1}{2}} k \right) r' \quad (3)$$

For the jet:—

$$Q = c H^{\frac{1}{2}}$$

$$R'' = \left( \frac{1}{2} H^{-\frac{1}{2}} c \right) r'' \quad (4)$$

$$\frac{R'}{R''} = \frac{\frac{3}{2} h^{\frac{1}{2}} k r'}{\frac{1}{2} H^{-\frac{1}{2}} c r''} = 3 h^{\frac{1}{2}} H^{\frac{1}{2}} \frac{k r'}{c r''} \quad (5)$$

8 For a convenient application of the above formula — it was found by experiment, that an 8" pipe discharged approximately the same quantity under a 6 foot head, as a 3 foot weir discharged under an 0.5 foot head. Then

$$R' = \left( \frac{3}{2} \sqrt{0.5} \right)^{\frac{2}{3}} \times 3 \times 8.02 r' = 16.9 r'$$

$$R'' = \left( \frac{1}{2} \sqrt{6} \right) \cdot 349 \times 8.02 r'' = 0.6 r''$$

Now suppose, as will be shown hereafter, that the jet head can be measured to .01 ft, while the weir head can be measured, with comparable accuracy, to .001 ft. Then  $10 r' = r''$

$$R' = 1.7 r'' \quad \frac{R'}{R''} = 3 \quad (\text{nearly})$$

$$R'' = 0.6 r''$$

which makes the jet approximately three times as accurate as the



weir, under these conditions.

The following pages will show that the jet meter, under high heads, can be as accurately read as mentioned, while, under low heads, where the weir measurement would be almost completely useless, owing to surface tension, slight differences of elevation of weir, etc., the jet is at its best, being measurable to thousandths, making the relative accuracy at least .30, and, owing to the above mentioned low head weir defects, probably much higher.

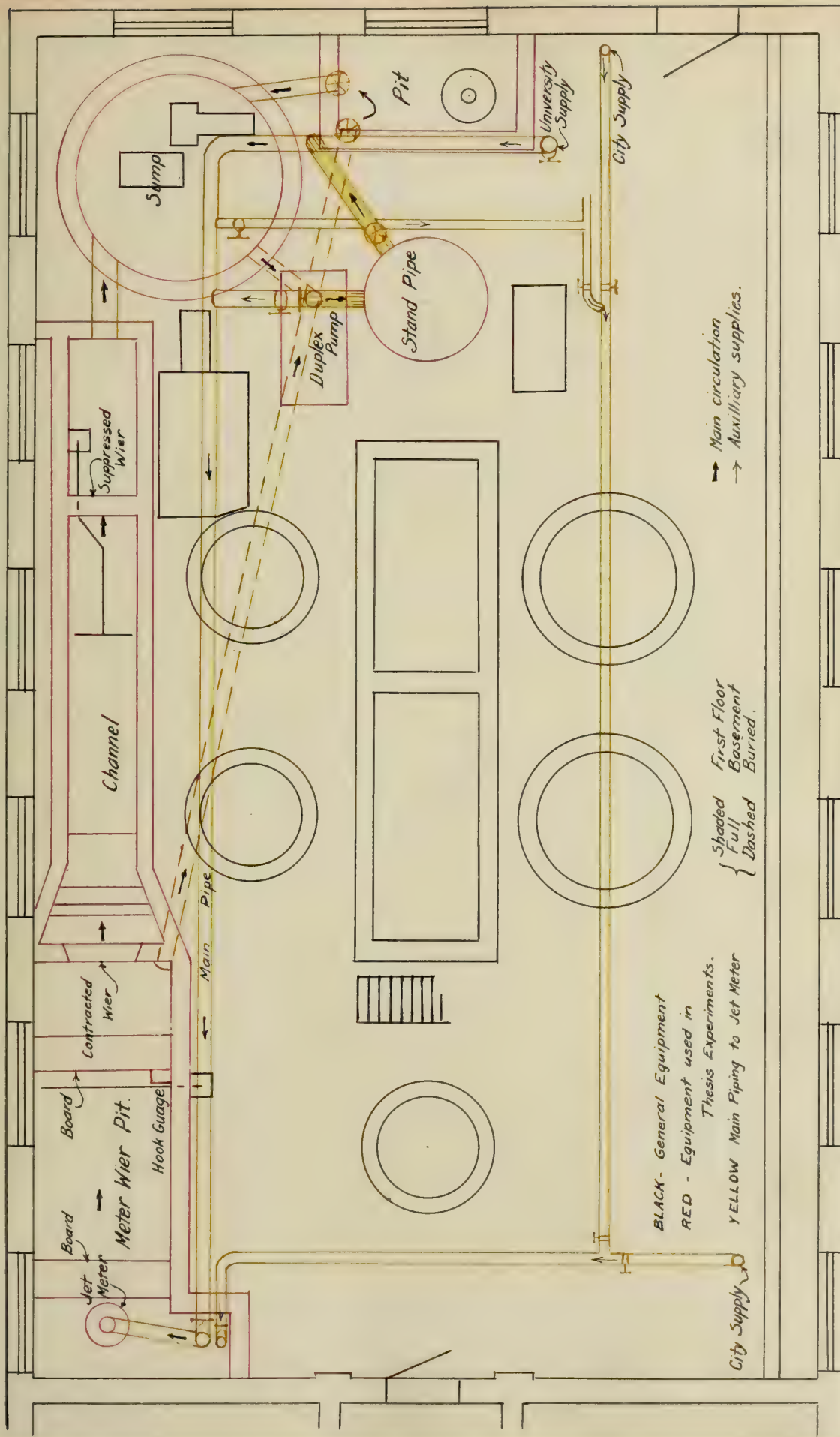
### Preliminary Design.

Authorities. The advantage of the jet meter has caused considerable experimenting to be made on various forms. The principal attempts have been made by the United States Hydrographic Survey. The writers have obtained what suggestion they could from valuable experiments by F.E. Lawrence and P.L. Braumworth of Cornell University, and by C.V. Seastone '95, under the direction of Professor Talbot of the University of Illinois, and, by quite an extended system of experiments, have endeavored to find the factors entering into the design of such a meter, and to ascertain the most accurate and practicable form. In this way their experiments differ from those of the above mentioned investigators, who, at least as far as is stated, made experiments on only one type.

Location and Facilities. After some study, it was decided to run the experiments in the basement of the Hydraulic Laboratory, where the pump and measuring devices would be handy. In



# I BASEMENT AND PIPING PLAN 77'-6" x 46'-6" HYDRAULICS LAB. APPLIED MECHANICS BUILDING, UNIVERSITY OF ILLINOIS.



SCALE  $\frac{1}{8}" = 1ft.$



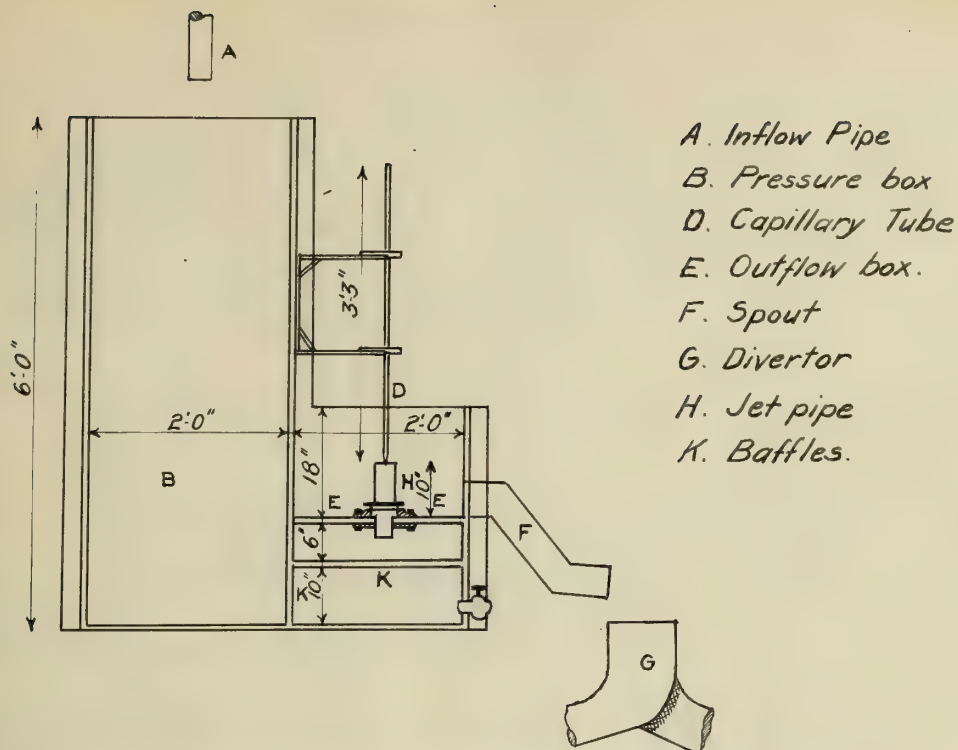
the North West corner of the room is situated a large, deep, and rather irregularly shaped concrete pit, having an area of about 180 sq. ft., and a depth of about five feet, above which connection could be made to a 12" pipe, thru which water could be obtained from the pump and standpipe thru two different routes.

12 At the East end of the pit, with crest 3 feet above the bottom, was a three foot steel plate contracted weir, capable of carrying a head of over one foot. A fall of  $3\frac{1}{2}$  feet occurred below this, then, after a level stretch of 25 feet, was a three foot steel suppressed weir, below which, after a fall of about  $2\frac{1}{2}$  feet the water discharged into a sump, from which it could be pumped, making the operation continuous. The pump was connected to the standpipe, from which one of the mains above mentioned led to the North West pit, heads up to 50 ft at the standpipe gage (65 feet in the pit) being obtainable. The above mentioned pump, a double cylinder, direct connected duplex steam <sup>pump</sup>, with 14" stroke and 16" water cylinders, could be enforced by a large turbine pump if necessary. The other route could be connected to the pumping station direct, and was used when necessary, to change the water.

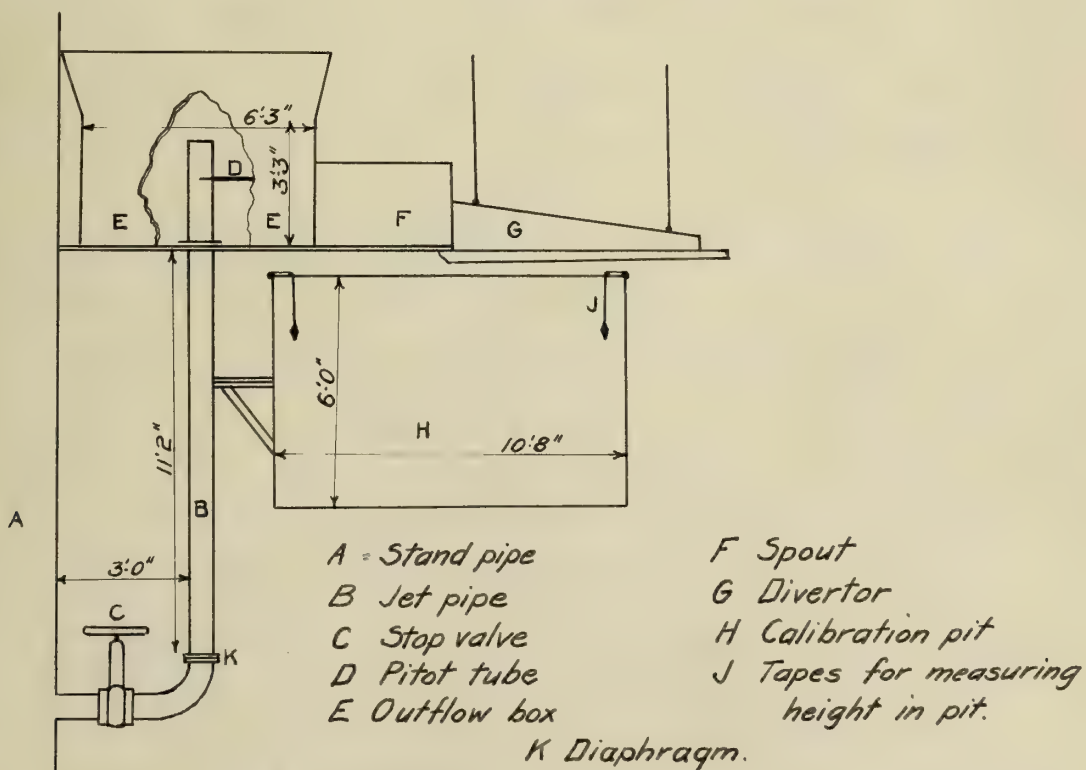
13 The admission of steam to the small pump was governed by a device whose action depended on the water pressure in the standpipe, and by means of which, when a weighted lever was properly adjusted, the standpipe level could be kept at any desired point.

Factors entering into the Design. After some consideration, we may divide the points in the design of a jet meter into three groups.





II. C.L. SEASTONE, UNIVERSITY OF ILLINOIS -1899.



III. F.E. LAWRENCE & P.L. BRAUNWORTH, CORNELL UNIV'Y. 1905.



(I) Design of approach pipes and connections.

(II) Design of discharging pipes and connections

(III) Design of head measuring apparatus.

15 Added to these, in the experiments, there was the fourth factor, of determining the most practicable way to measure the jet discharge.

16 In none of the work was theoretical accuracy allowed to prevail over practicability and convenience of operation, indeed, many schemes, valuable in the laboratory, were abandoned because of uselessness at the reservoir, or mining site.

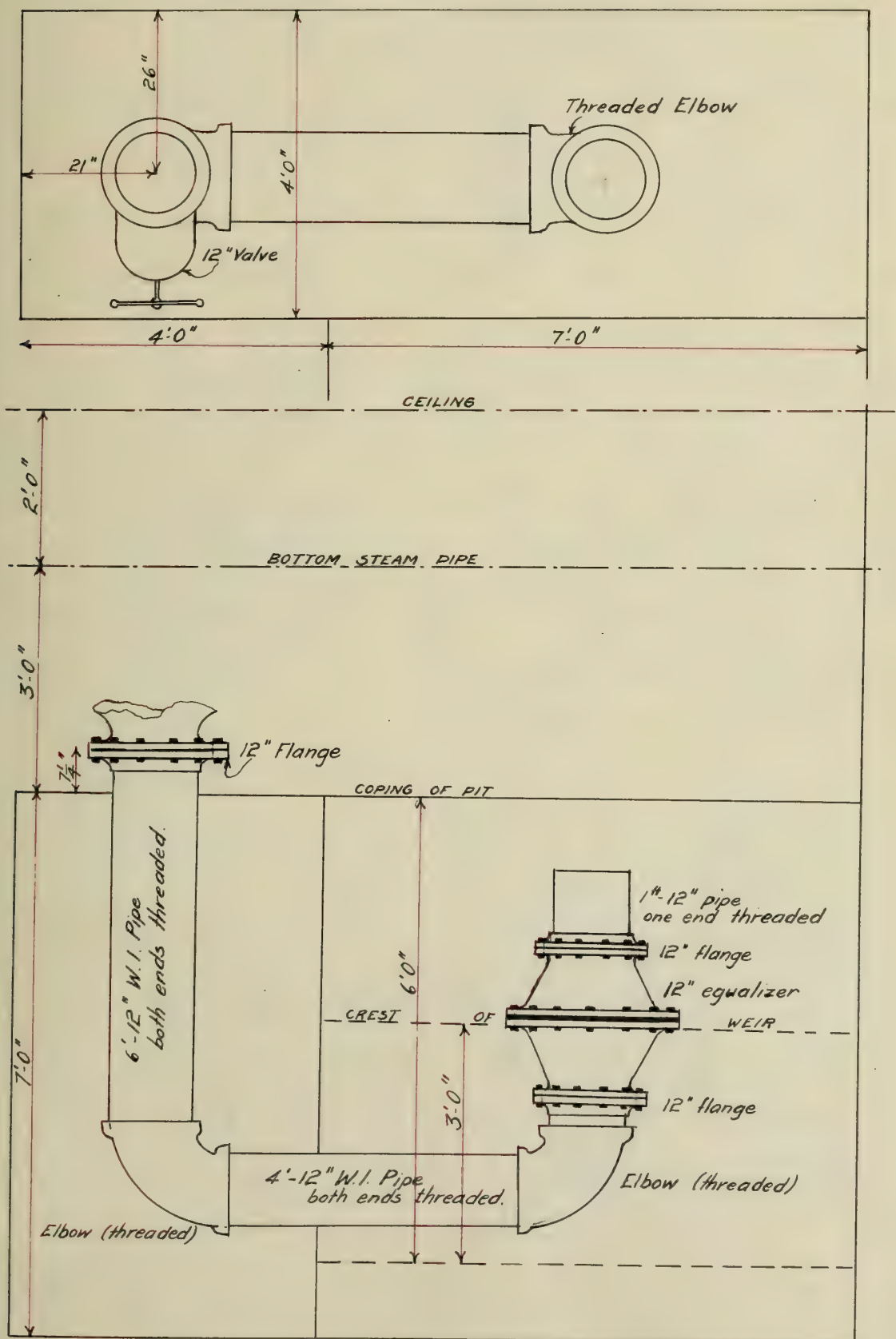
17 Before starting actual work, a large number of different plans were considered. That used by Mr Seastone, a large wooden box with baffles (Fig II, also Technograph p 98, V. 14) was, after running a few tests, rejected as being entirely impracticable for large measurements, owing to the size of box necessary to contain the water to supply a discharge, and the impossibility, under practical circumstances, of securing a sufficient head. As it will be seen later, however, valuable suggestions were obtained from his method of measuring the head by means of a graduated tube. The Cornell Experiments (Fig III, also Report of American Society of Civil Engineers V ) very carefully performed, gave many suggestions. The plan of a direct measurement of pressure head, however, was deemed impractical, while, on the other hand, both plans for velocity head measurement, by means of sighting rods and Pitot tubes, were tried.

18 In view of the above considerations, a plan proposed by



# IV APPARATUS IN PLACE

12" SHORT TUBE IN USE (SEE ALSO FIG. . .)





Professor Talbot was at last adopted, which consisted in the use of a double expander as shown, having, for a pipe of diameter " $D$ ", a greatest diameter of  $\frac{3}{2}D$  and a length of  $2D$ . One of these is shown in Fig IV. Three of these, for 4", 8", and 12" pipes, of cast iron, were ordered, their delivery in January marking the beginning of active experiment. It may be mentioned that galvanized iron sections, after consideration, were abandoned on account of lack of durability, altho much cheaper than the cast iron. The plan of connecting this apparatus is also shown in Fig IV.

19 It will be seen that an elbow in the pipe so close to the discharge, would cause an undesirable variation in flow across the pipe section, which the expanded section could hardly be hoped to obviate. This necessitated a careful consideration of baffles, which continued almost until the last day of experiment.

20 One baffle, however, was left in during the entire course of experiments - a  $\frac{3}{8}$ " circular steel plate, perforated with  $\frac{3}{4}$ " holes, one inch center to center, which was bolted between the flanges below the expanded section. In addition, a baffle at the greatest section was thought desirable, and conditions of steady flow dictated that the holes should be tapering. The size of holes which was attempted at first, and still recommended, altho not used, was 1" square, tapering to  $\frac{5}{8}$ " square. After some difficulty a  $1\frac{1}{2}$ " wood baffle, with holes  $\frac{3}{8}$ " square, tapering to  $\frac{1}{2}$ ", was constructed by burning the holes out. The success of this baffle would depend entirely on the clearness of



the water:— even under the comparatively good laboratory conditions much trouble was experienced from clogging, and larger holes would have been greatly desirable.

21 The only general form of discharge apparatus considered at first was a small length of straight pipe. It was decided that pipe of length "D", bolted to the top flange of the expanded section would allow length enough for a steady flow to obtain, and, at the same time give a standard condition. It was planned to use 4", 8", and 12" pipe as before mentioned. Subsequent experiments, to be taken up here after, discovered a more desirable form of discharge apparatus.

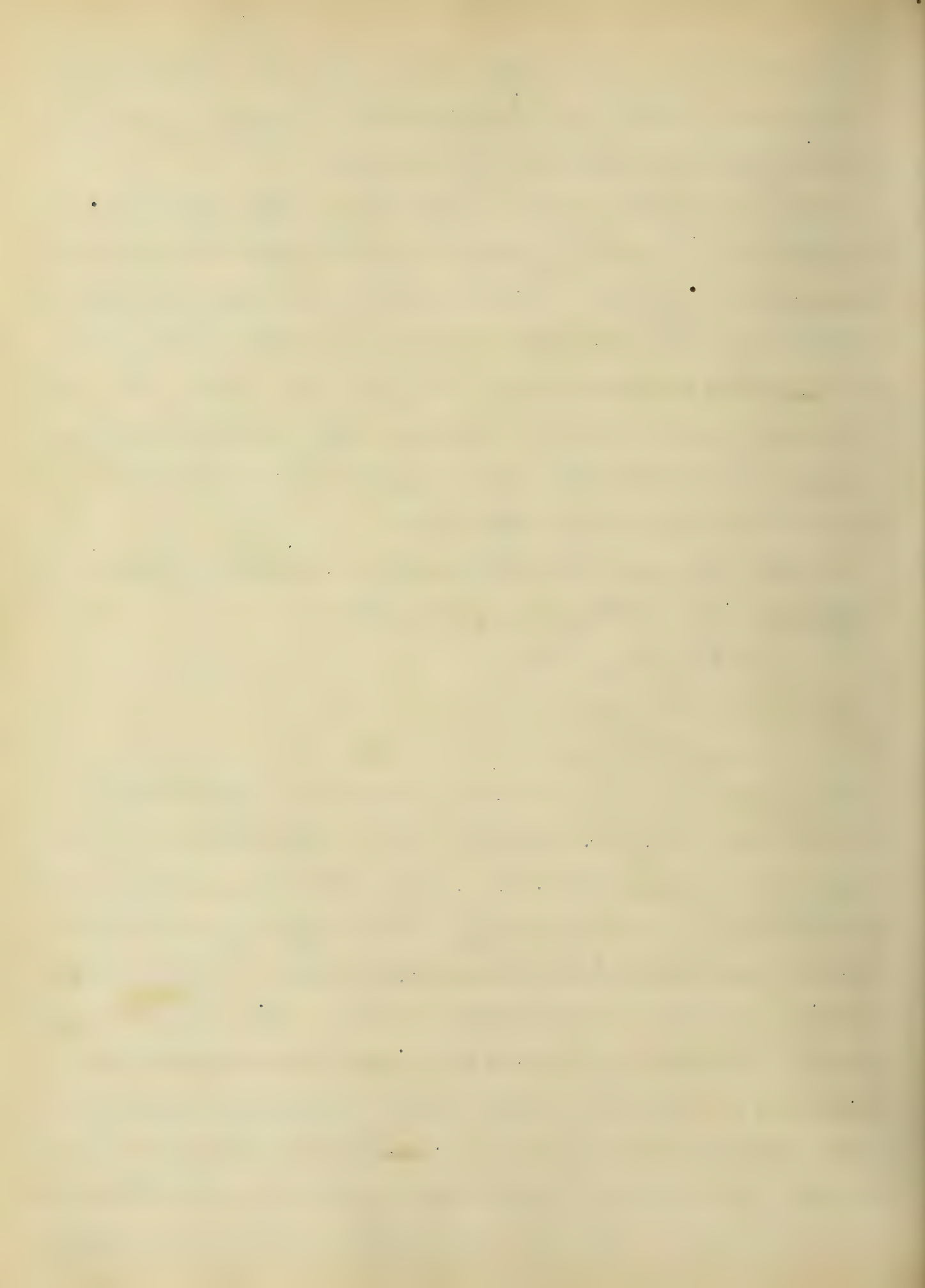
22 One of the most difficult questions was that of measuring apparatus. The following were considered:

(I) Capillary tube.

(II) Pitot tubes.

(III) Lighting rods.

After consideration, it was decided to abandon the last for a time (it was subsequently taken up). A short tube,  $\frac{1}{2}$ " in diam. was used, being secured to the ceiling of the room and by wire at the bottom. A wooden plug, with a capillary duct cut thru it, was secured at the end of the pipe, and prevented excessive oscillation of the water column. The measurements were to be taken by means of a scale placed in the tube. This form of apparatus, which gave highly satisfactory results in a rough preliminary test, was subsequently much improved, as will be described. The Pitot tubes, in the form of a Pitometer were carefully studied, but, in the preliminary experiments

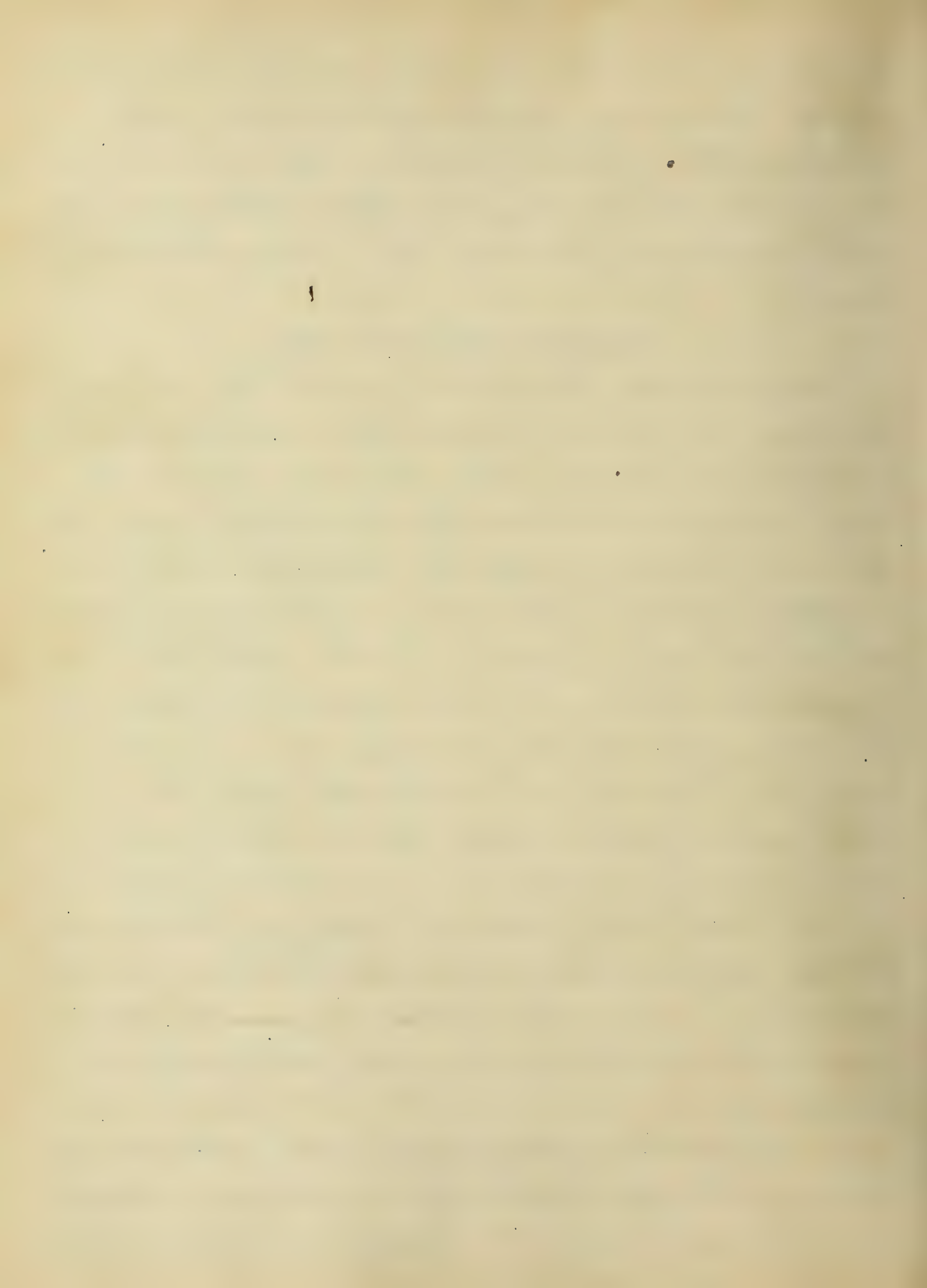


were not tried, as the drilling of a hole in the pipe thru which to insert them was undesirable, and, owing to the overflow direction of the water at that place, they could not be held over the top of the pipe. They were tried a little, however, in making a preliminary traverse, with no success, for the above reasons.

### Experiments with the Short Tube

Conditions of Flow. In the form in which the meter was first conceived - of a short vertical tube - it was necessary to carefully consider the form of the discharge. The fact is known that under low heads the flow at the top edge of the tube would be normal to the axis of the tube, or that the overflow would be exactly similar to that from a weir, and that the discharge would be comparable to that obtained from formula (2), using " $b$ ", as the circumference of the tube. It is known that as the head on a weir is increased, the water first clings as a sheet to the weir board, then air flows in below this sheet, and after that the flow is normal to the face of the weir. Little is known about the clinging condition - it is the condition obtaining after the intrusion of the air which has been studied out and formulated. However, <sup>in the jet</sup> as in a weir, the clinging condition does not last long, and the heads under which it obtains, in any case, are too small for practical use.

24 As the head is increased, the weir condition above described continues awhile, then the flow becomes disturbed, and bursts up in places, these upbursts becoming more numerous as the



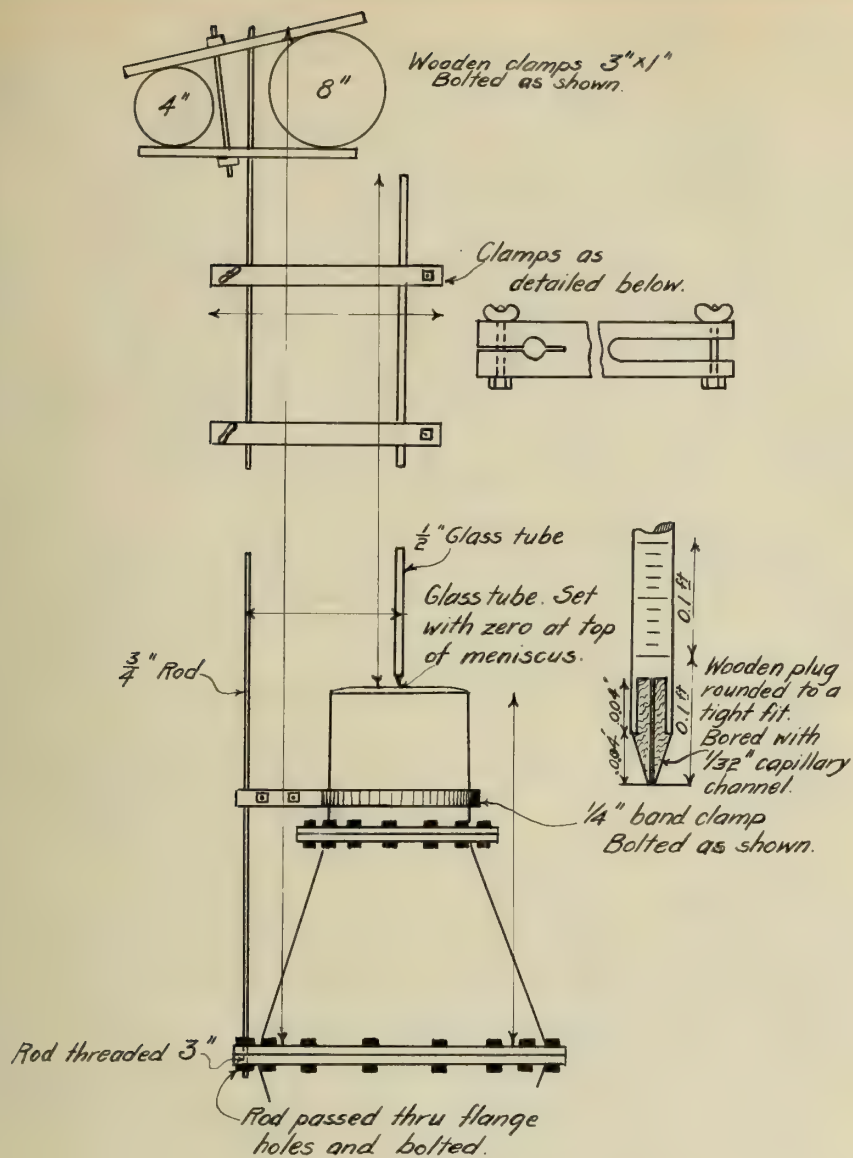
head is raised until a point is reached at which the entire flow changes suddenly, becoming parallel to the axis of the tube. After this the flow can reasonably be called a jet, and the discharge should be comparable to that obtained by formula (2).

25 Altho the point of transition would certainly never be used as a desirable measuring point, yet it was necessary, for completeness, to study this point carefully. It is easily seen, from the form of equations, that a graph of a whole series of experiments would be represented by a reversed curve, the two sections of which would be of the exponential form, and, if plotted on logarithmic paper, would take the form of two straight lines of different inclinations. It was mainly for the purpose of verifying this prediction that the preliminary run was made.

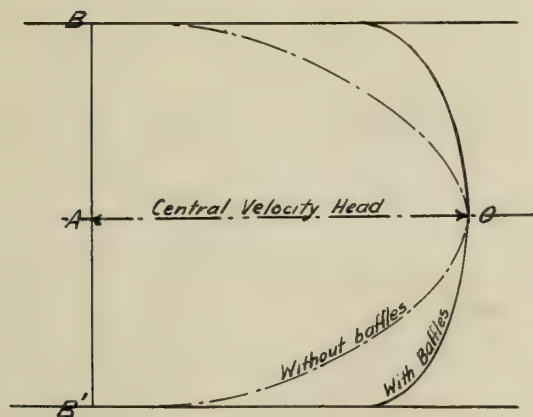
Preliminary experiments. Under this head will be classed those experiments performed before Mr Marsden entered upon his work, and before the introduction of the baffles into the apparatus.

27 The pipes were joined as in Fig. IV without the baffles, the orifice tube being  $8\frac{1}{8}$ " in diameter. The measurements of head were taken; for high heads by means of the  $\frac{1}{2}$ " tube before mentioned, and for low heads by means of a pitometer held over the top of the tube. Altho both devices interfered noticeably with the smoothness of flow, the results obtained were very consistent, plotting in just the expected manner. (See Pl I). The two conditions, and the point of transition





# V CAPILLARY TUBE APPARATUS FOR MEASURING HEADS.



# VI EFFECT OF BAFFLES ON DISCHARGE.



are shown beyond chance of mistake. The water measurements in this case were made over the suppressed weir. The lack of baffles was noticeable in both conditions, the flow being higher on the side opposite the elbow, and being disturbed by bubbling and trembling. It was well seen that the methods of measurement were crude, being inconvenient to the point of impracticability.

28 Following this run the steel baffle at the bottom of the expanded section, and the wooden baffle at the middle were placed in position. As the following investigation was entirely by observation, its details will be considered in the order of their occurrence.

Experiments with Baffles in Position. By Feb. 11, 1908 both baffles were bolted into position in the pipes, and a set of readings taken with the 8" shot tube, measurement of head being by means of the capillary tube.

30 It had been evident, from the preliminary experiments that some method would have to be devised by which to hold the tube rigidly, and yet to give support high enough above the tube so as not to interfere with the jet. It was attempted to design a standard which should be light, and yet as strong as possible, and, as a result, the apparatus shown in the accompanying diagram, and which explains itself (Fig V) was made. The bracing at the top was found necessary to avoid vibration. As far as stability and convenience goes, this device was satisfactory. The tube used was six feet long, graduated by etching to feet,



tenths, and hundredths, in such a way that when the plug shown was in place at the lower end, its tip would be at zero. In setting the tube it was first very carefully centered with the orifice by means of the motion of the wooden clamps, then moved vertically until its tip just touched the surface of the water, when the latter was at the point of spilling over the edge. The same method was used each time the tube was set.

31 Set 3 was primarily a study of the weir and transition conditions of flow. It will be seen that the weir condition, represented by a power of  $H$  greater than one, is convex downward, while the jet condition, represented by a fractional power, is convex upward, (Plate II) the transition period being represented by the point of inflection. Again, as in the first run, the jet and weir conditions were comparatively smooth, but the transition flow was disturbed. As might be expected, the transition for each separate filament of water is instantaneous, the disturbance being caused by the interference between filaments, since not all having the same instant of transition, some will be in the jet condition while others are still in the weir condition. It is hard to tell why these irregularities should occur, but small differences in water and air pressure at different points in the jet would be sufficient to cause them. The transition period in this run seemed to occur while the head on the jet was between 2.5 and 3.5 feet.

32 It may be here stated that a short run was later made



using both baffles in a 12" short tube apparatus. The results will be found in Table 19, at the end. The coefficient in this later test was larger than that with the 8" pipe, which might be expected. This run will be mentioned later, in connection with the office tests on 12" tube.

Conclusions regarding the Use of Baffles. At first sight of the flow it was doubted whether any improvement had been made over the first experiments, without the baffles. It will be seen from Pl II that the curve with baffles shows a greater discharge than without. The reasons for this will be evident from a study of Fig VII. The broken line represents, diagrammatically, a traverse of the tube without baffles; the full line the more uniform cross section produced by the baffles.  $\overline{AO}$  is in each case the central velocity, measured with the capillary tube. The areas between each curve and  $\overline{BB'}$  represent, graphically, the unit flow under each condition, and, evidently, the baffles produce a greater flow. This is, of course, of advantage.

34 It will also be seen that the lower heads, for both conditions, are most affected by the baffles, as would be expected, since the baffles, under those conditions would be more efficient in equalizing the flow.

35 Plate III is a comparison of the coefficients of discharge with and without baffles; bringing out the same results as above explained. The coefficients were computed from the formulae:

$$C = \frac{\Phi}{A\sqrt{2gH}} = \frac{\Phi}{2.81x} H^{\frac{1}{2}} \quad (\text{for jet})$$

and

$$\Phi = cb\sqrt{2g} H^{\frac{3}{2}} \quad (\text{for weir})$$



where  $c$  = Coefficient of discharge  
 $Q$  = Discharge (cu. ft. per sec.)  
 $A$  = Area of pipe (sq. ft.)  
 $H$  = Head on center of pipe (feet)  
 $b$  = Length of weir edge =  $\frac{8\pi}{12}$

The quantities ( $Q$ ) used in these plates were obtained from a carefully constructed head - discharge curve for the weir in use.

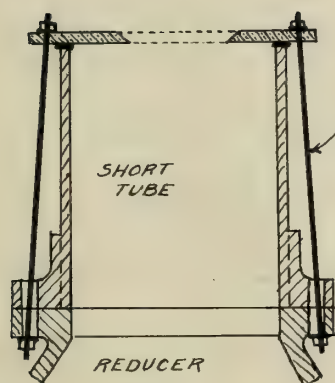
### Experiments with Orifices

Considerations leading to use of orifices. It was found at this time, by means of a series of traverses, obtained by swinging the bottom of the capillary tube across the top of the pipe, that the conditions under which the jet was flowing were by no means satisfactory. The bend in the pipe seemed to affect the jet even after the water had passed thru the two baffles before described. The velocity indicated towards the outside of the curve was very high, while towards the other side it was low, and, in addition, the edge velocity at the inside edge was greater than that a short distance from the edge. It was determined that if the scheme were to be practicable, and at the same time accurate, this must be remedied. There were at least three alternatives (1) Increase the number of baffles. (2) Change the arrangement of holes. (3) Change the shape of orifice. It must be remembered that this bend in the pipe which caused the trouble was not an exceptional case, but very likely to occur in practice.



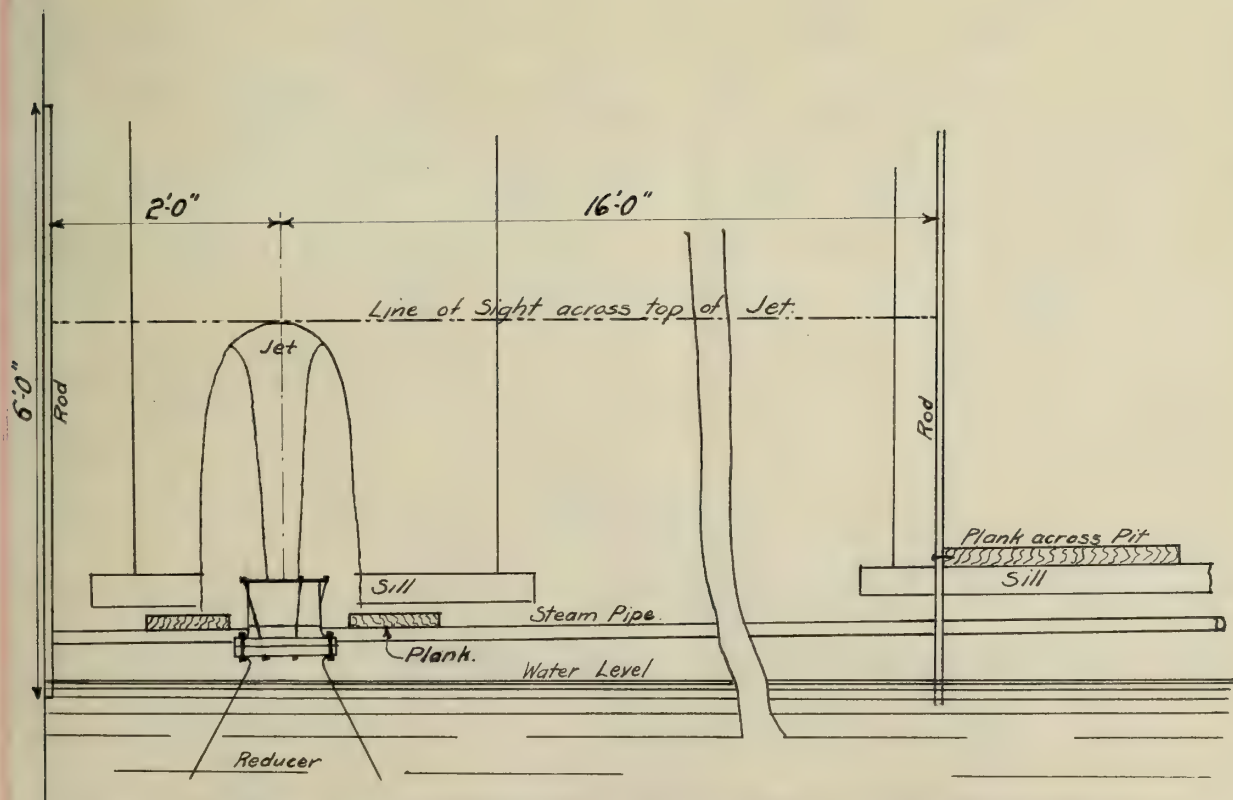


VII 6" ORIFICE ON 8" REDUCER.



1/4" Rods, stuck thru  
bolt holes in reducer  
flange, and bolted.

VIII 6" ORIFICE ON 8" SHORT TUBE.



IX GENERAL ARRANGEMENT OF SIGHTING ROD APPARATUS.



37 In increasing the number of baffles, the idea of having one between the short tube and the reducer was considered, this to be of the same general design as that below the reducer. (the steel plate baffle). Two objections - first the general one, against complication, and, second, that if the baffle were so close to the orifice the jet might consist of several small jets instead of one large one - caused this scheme to be abandoned.

38 The second alternative was not as thoroughly investigated as possible, principally for lack of time, so something might be possible along that line hereafter. In any case the baffle holes should not be smaller than described, since, as they were, they collected a great amount of debris from the water, which clogged them up, noticeably reducing the head for a given standpipe pressure. If larger, the holes might be better fitted, altho, ~~if larger, the baffle plate must be~~ ~~thinner~~ ~~to give the requisite uniformity, since they are~~ ~~already too large for good use with said thickness.~~ A combination of diaphragms in the pipe and in the reducer would help, altho all such would tend to increase friction, of course.

39 However, there is, in the term "vertical jet" no specification for a short tube jet. It will be remembered that an orifice gives a much smoother stream when discharging horizontally than a short tube since it tends to throw the water together, while a short tube, on account of more or less exhaustion near its edges, tends to spatter the jet as it emerges.

40 It must be remembered, however, that the following



objections obtain to an orifice so used - (1) The contraction is not perfect, so, if calibration is attempted, this must be taken account of. (2) The condition obtaining before the flow breaks into a jet is hopelessly involved, since the outflow adheres to the top of the orifice plate for a time, and the duration of this condition depends somewhat on the size and thickness of the plate. On account of the last fact it was considered useless to experiment on the adhering flow, and all that was done in the following experiments was on the jet proper. The theory of the adhering flow would needs be, for the present, merely a matter of obtaining coefficient tables for various sized plates and orifices under various heads. The comparative advantages of short tube and orifice will be discussed in the conclusion.

Head Measurement by Level Rods. Before proceeding with the orifices a new system of head measurement was devised. The capillary tube, altho quite efficient, caused great inconvenience in reading, and, under the conditions necessary for reading, it was doubtful whether acceptable observations could be made, since the observer, with high heads, was deenched from head to foot.

42 In conducting the Cornell experiments two sighting rods were used, set on opposite sides of the jet. A horizontal line of sight across the top of the jet would give equal readings on both rods. The level of the orifice being determined, the heads could be read directly. The disadvantages of this method are, the neglect of atmospheric friction and the inaccuracy of reading an oscillating head without provision for



damping the oscillations. The first objection is met by saying that if the method is used in practice, the atmospheric pressure would be taken account of in the coefficient, and that the available velocity head is the only actual necessity. It was found that it was a comparatively easy plan to average the height of head; much easier with the large oscillations observed at a distance than with the small ones, obtaining in the capillary tube, which had to be observed from near the tube.

43 There was, however, a noticeable improvement made over the Cornell method. While, in the latter the rods were equidistant from the jet, and great care was necessary to equalize the rod readings, in this series the rod near the observer was 10 times as far from the jet as the other one, so that an error of  $\frac{1}{10}$  foot in the height of the observer's eye (which could hardly take place with ordinary precaution) would only cause an error of  $\frac{1}{100}$  ft in the observed value of the head. The rods were graduated to the same datum by means of the water surface in the pit. The zero reading was obtained by extending a carpenter's level between the orifice edge and the nearer rod. The whole setting is shown in Fig. II. It was proposed to use a sliding square on the nearer rod, but this was abandoned on trial, on account of difficulty of management.

Arrangement of apparatus. (See page 3). On this page is a discussion of the relative accuracy of weir and jet. Strange as the results may seem, they were predicted by observation.



It was soon found that the weir calibration for the jet was almost as bad as useless, since the latter was so much more sensitive than the former. The jet head might vary almost a tenth without the weir showing any change.

45 It was decided to remedy this by measuring the flow directly into the pit in which the meter stood. A careful calibration was made of it, by letting weighed quantities run into it and determining the rise, and a coefficient of 0.1792 cu. ft. per 1000 ft rise was obtained. This was checked by measuring the dimensions of the pit, calculating its area, and subtracting the horizontal cross section area of all pipes, baffles etc., obtaining a coefficient of 0.1788, so close a correspondence as to lend great strength to all sets employing the pit.

46 The first method of procedure was to drain the pit, close the drain valve, take a gage reading, rapidly open the meter valve, and note the time of starting with a stop watch, allow the meter to run until the pit was fairly full, close the meter valve quickly, noting time with stop watch, allow water to quiet, take gage reading, allow pit to drain, etc. This method was open to the following serious objections; (1) The time of starting and stopping runs could not be accurately determined, owing to the time necessary to open and close the valve (2) All readings obtained were in uneven decimals, complicating computation.

47 To obviate these difficulties, the hook gage was later enclosed in a still box. The procedure then was:— Have gage set at .000, drain pit to considerably below



gage point, open meter valve to desired amount, allow water to rise, noticing time when it reaches .000. Set hook gage at any desired higher reading, again note instant of hook submergence, shut off meter valve, drain pit, etc. It will be seen how much more convenient this is than the former plan, and how it remedies its objections.

48 The rods being fixed, the matter of orifices was taken up. A 4" orifice was first bolted to the top flange of the reducer, heads of bolts thru the latter engaging the edge of the orifice plate. Before the results were computed, the following change was made; The 8" tube was inserted, and the orifice plate bolted to its top by means of long bolts engaging the reducer flange (Fig VIII). In this way very complete sets of readings were taken, using both dropping and stationary heads.

#### Results of Experiments

49 Plate IV illustrates the range of coefficients of a 4" orifice. It will be seen that the curve follows the same general form as that for the flow from the short tube, except that it does not rise so high. The average value for the coefficient on the horizontal part of the curve is .641

50 On the same sheet is plotted a curve showing the coefficients obtained when the orifice was bolted directly above the reducer, without the intervening piece of pipe. It will be seen that this curve lies below the former (average value = .627). This can be accounted for by saying that the effect of the shape of the reducer top is the same as <sup>would be obtained by</sup> having a larger tube below the orifice. It has been attempted to show this diagrammatically



in figure 5. This reason, besides the fact that the form used in this test would be more difficult to duplicate than the form with the short tube, and would possess no advantages over it, led to the decision to omit it hereafter.

51 Plate V shows the same results, the upper curve being that obtained when the 8" short tube was below the 6" orifice. This exhibits the same form as that obtained with the 4" orifice, except that it rises higher (Average .679). The lower line was obtained with the 6" orifice directly above the reducer. The coefficients are again lower than those obtained above, averaging .650.

52 During the following days the 8" tube and reducer were taken down and the 12" apparatus (Fig II) set up in their place. A steel baffle (Fig II) such as was described before was inserted at once below the reducer, but the baffle between the two reducer tubes was not inserted at once. Three orifices were provided, being 8", 10" and 11" in inside diameter. An improvement over the ordinary form was in a shoulder turned on the bottom of the orifice plate (Fig II) which set down into the short tube, making a much better joint.

53 The wooden baffle, afterwards inserted between the two reducer tubes was 2" thick, and 26 inches in diameter (Fig II) being bolted between the flanges as was the case with the baffles used in the 8" apparatus. There were 200 holes in the baffle, each being  $\frac{5}{8}$ " square at the upper end, and  $\frac{1}{2}$ " square at the lower, thus making the holes smaller

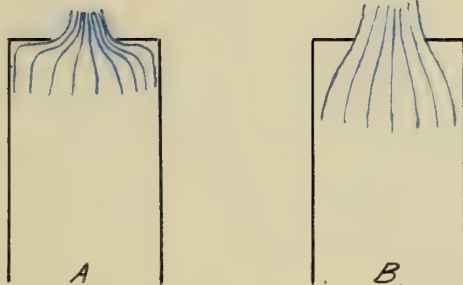
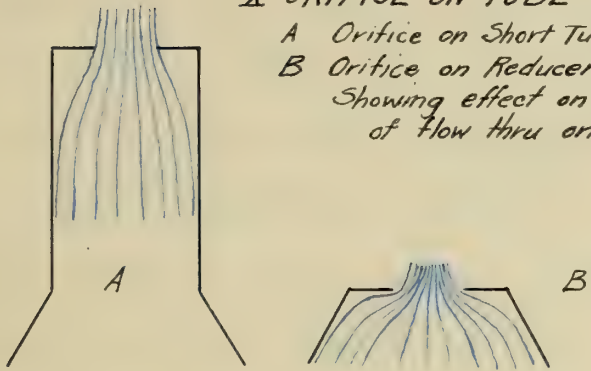


### *X ORIFICE ON TUBE & REDUCER.*

*A Orifice on Short Tube.*

*B Orifice on Reducer*

*Showing effect on direction  
of flow thru orifice.*



### *X DISCHARGE UNDER HIGH & LOW HEADS.*

*A = Orifice discharging under low heads.*

*B = Orifice discharging under high heads.*

*Showing effect of direction of flow  
thru. orifice.*



than those used in the 8" apparatus baffle.

54 Sets of readings were taken in the following order (1) 8" orifice without wooden baffle, (2) 10" orifice without wooden baffle (3) 8" orifice with wooden baffle, (4) 10" orifice with baffle, (5) 11" orifice with baffle, (6) 12" tube without orifice. So little difference was noticed between the coefficients obtained with and without baffles, that but one curve was plotted for both cases.

55 Discharge readings were by means of the weir, for the quantities were so large that fair accuracy was obtainable by this method, and were too large to be handled in the pit. Special care was taken, however, in determining the zero reading, since it was found, in computing quantities by means of the 4" orifice, that a very small error in the former would make a very radical error in the coefficient of discharge.

56 Plate VII illustrates the results obtained with the 8" orifice on the 12" tube. The average ultimate coefficient is .642

57 It is here seen how the orifice affects the coefficient. The coefficient for the 8" tube was about 0.90; for the orifice of the same size it is 0.64. It is also to be marked that, while the insertion of the wooden baffle into the tube materially increased its coefficient, the same was not the case with the orifice. The reason for this is that, altho the pipe flow in both cases may be equalized to the same extent, the friction of the water in flowing around the orifice plate



may retard the outside filaments, causing them to move more slowly, and to return to somewhat the same condition as before the baffle was passed. Of course, the filaments are not thus retarded in the tube. While not so potent in equalizing the sectional velocity, the chief end of the baffle is to prevent jumps and bubbling in the discharge, and this latter it does, very effectually.

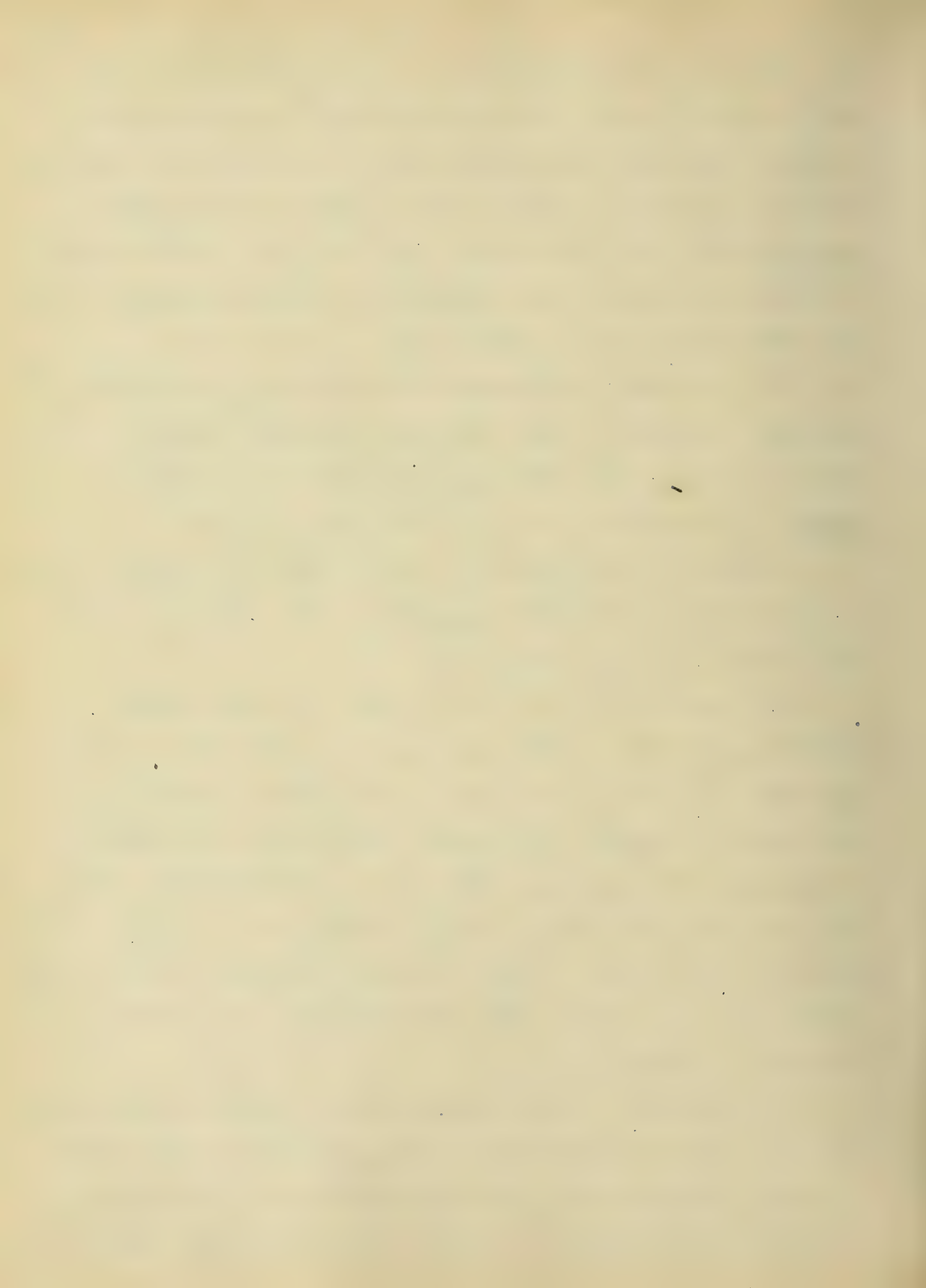
58 The next curve (Plate III) shows the range of coefficient with the 10" orifice. The average ultimate value is .706. The lower curve shows the effect of the use of but one baffle; the difference is seen to be very small.

59 (Plate IV) shows the range with the 11" orifice, the average value (estimated) equaling .78. This curve shows the utmost capacity of the pump.

60 The data obtained by using the 12" tube without orifice has not been plotted, since, owing to the limiting capacity of the pump, it was impossible to obtain heads of a practical size. The data will be found in Table 19.

Discussion of curve form. It is seen that all the curves have exactly the same form. Starting in a line radial to the origin, they continue as straight lines, nearly vertical, for a time, then they curve sharply, and become virtually horizontal lines.

61 One hypothesis for this special form is that, while under low heads the water fills the corner formed between the tube and orifice plate completely, thus approaching the orifice opening normal to the direction in which it must emerge, under the



high heads the flow adjusts itself so that the corners are not full, but the flow approaches at an angle with the axis of the pipe, not as great as in the former case. This condition is shown in Fig I, which shows the cause and effect much more effectively than any description would. Thus, as the condition of flow gradually changes, the coefficients increase rapidly, until the flow reaches an equilibrium condition, beyond which the position of the filaments remains the same, no matter how high the head is raised.

62 It may be useful, for investigation's sake, to notice at what heads, these various curves become horizontal:

Size opening	4"	6"	8"	10"	11"
8" tube	.75	.87	1.00		
12 tube			1.00	1.50	2.00 (estimated)

It will be seen that these results show considerable uniformity. It would be useless to attempt any further theoretical discussion here, but the above table would be useful in practice, to indicate the lowest head with which the ultimate coefficients, stated in the preceding articles could be safely used for these two sizes of pipe and various sizes of orifice.

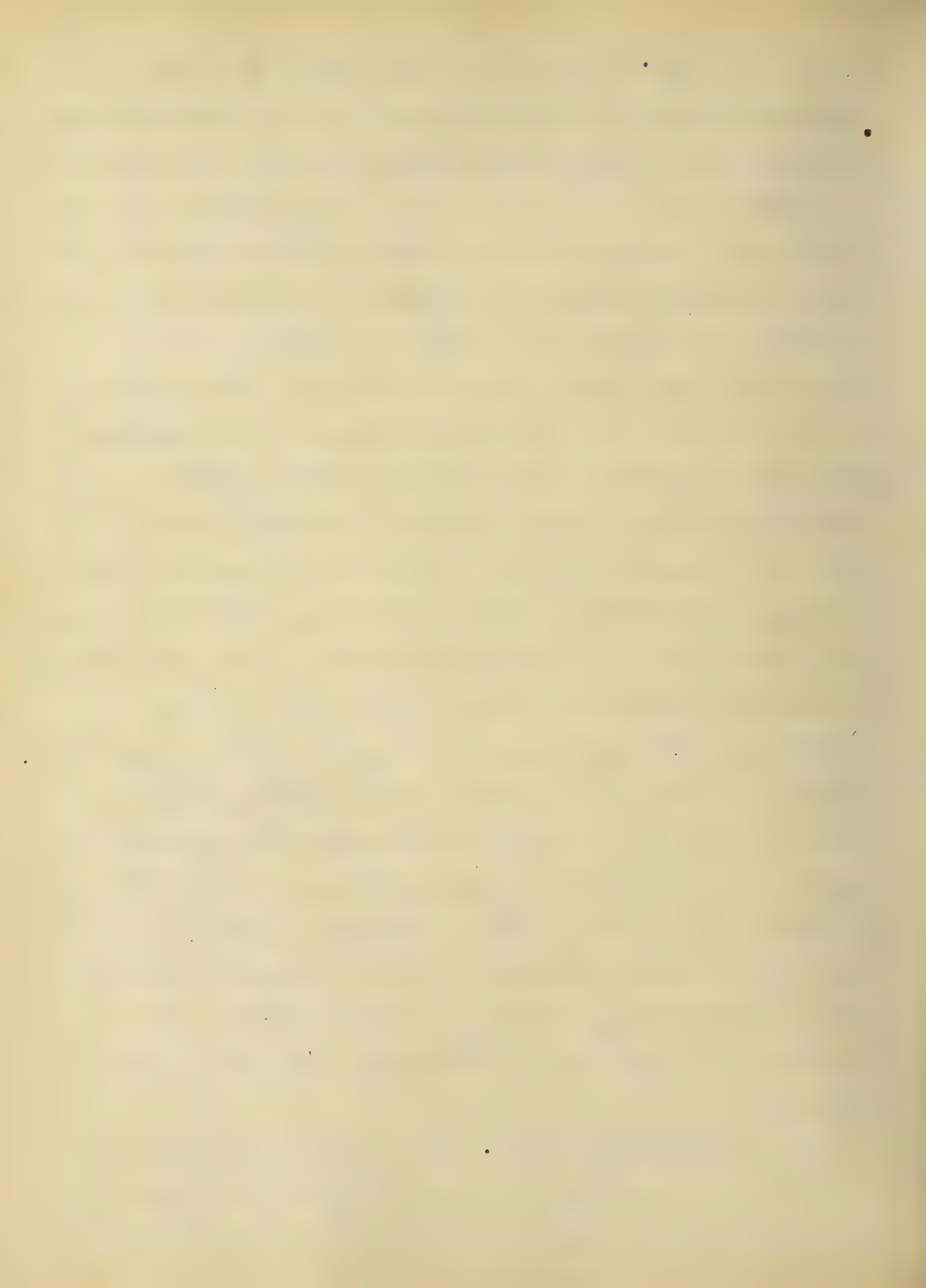
63 Probably the most important theoretical discussion relates to the effect upon the coefficients of various ratios of  $\frac{\text{orifice}}{\text{tube}}$ . Plate IX summarizes the entire lot of experiments. In this are plotted two curves, one for each size of pipe. The ordinates are the values of the ultimate coefficients, while the abscissa are the sizes of the orifices.



As the ratio  $\frac{\text{orifice}}{\text{tube}}$  approaches 1, the coefficients increase, and approach the value of the coefficient of a short tube alone, along a regular curve, showing that the two forms of flow are really the same.

64 Starting from .61, which it is important to remember is the coefficient for an orifice with complete contraction, the curve runs up to a very high coefficient. Complete contraction is theoretically obtained when  $\frac{\text{orifice}}{\text{tube}} = 0$ . If the 8" curve is taken, we have the point  $\frac{0}{8} = 0$ , at which point the coefficient is .61 as it should be. When the ratio is 1, the coefficient approaches closely to 1, as would be expected, altho owing to well known practical causes, it never completely reaches that value. The smoothness of these curves is an excellent check on the general value of the separate results. Other curves could be sketched into this plate, if desired, and, by keeping the two points (0;.61) and (1;1) fixed in their positions, and maintaining the same general form of curvature, very close approximations could be made to the coefficients for any combination of tube and orifice. It would be very desirable, however, to have further experiments made along this line, to ascertain the truth of these suppositions as to the form of curve. On Plate I curves have been drawn as directed above, for several standard sizes of pipe, and it is confidently prophesied that experiment will closely verify the values shown there.

Discussion of equation form. Various exponential equations have been used, at various times, to express the discharge from a jet, orifice, or tube. These may include the size of



the discharge opening, brought in either as a factor with a fractional exponent, or as an exponent to the term expressing the head. While these equations may have their place, it certainly is not in a practical discussion. The water supply company cares nothing to have the size of a pipe included in a formula - it is simplicity they are after. The formula:

$$Q = A \sqrt{2gH}$$

has been often shown to be theoretically correct for a vertical jet. Those conditions which cause the variation from this formula are due to contraction, air friction, weight of falling water - all being conditions which are, at present, beyond the reach of theory, and, since that is the case, it is decidedly impractical to attempt to express them theoretically. The use of a coefficient is the most sensible way to express these variations. Then:

$$Q = c A \sqrt{2gH}$$

Where  $Q$  = discharge in cu. ft. per sec.

$A$  = Area of orifice section, in sq. ft.

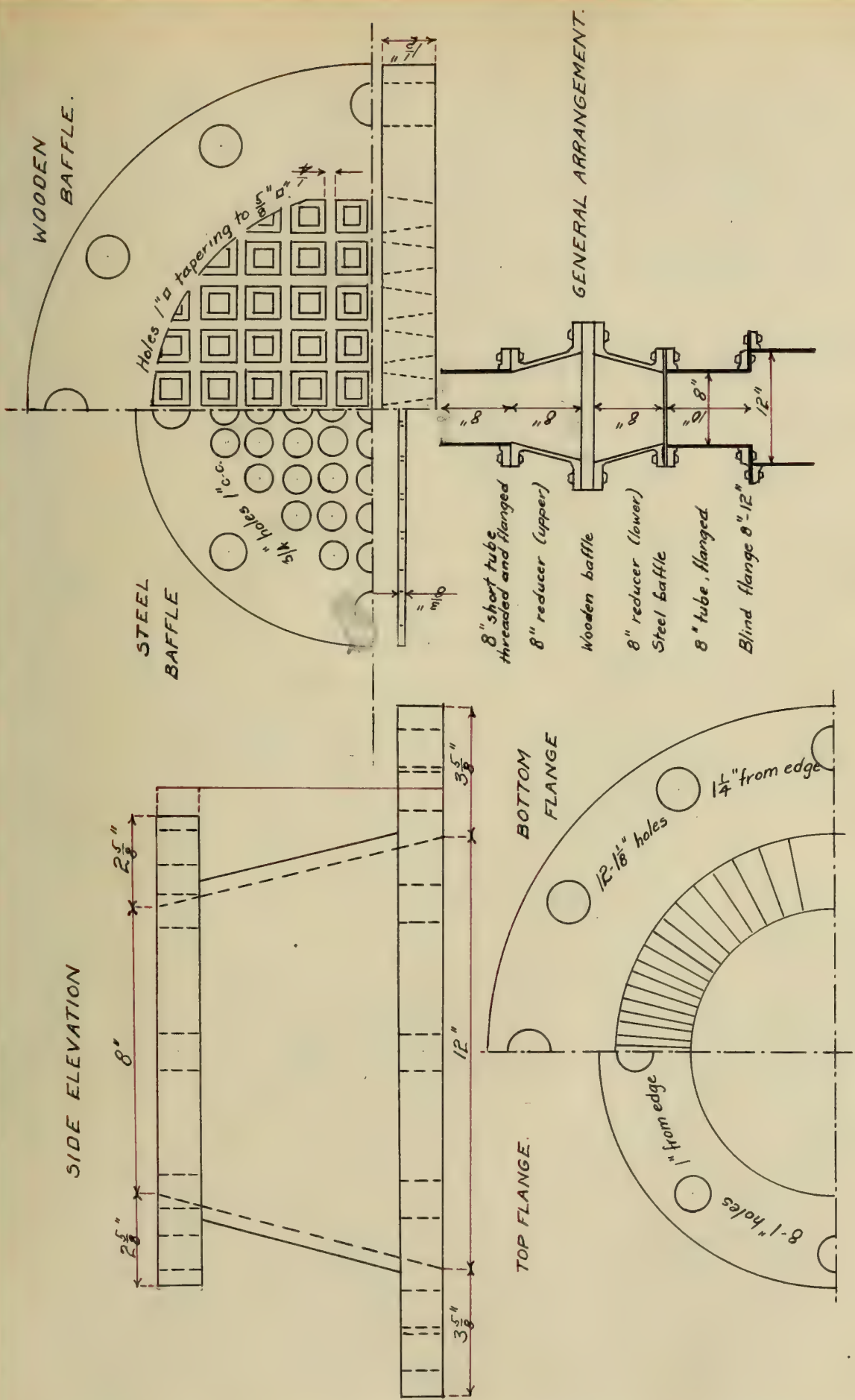
$H$  = Head on orifice, in feet

$$g = 32.2$$

$c$  = Coefficient obtained from test data.

is recommended as the formula to be applied to the jet meter.





XI. DETAILS FOR DISCHARGE TUBE FOR 8" METER.

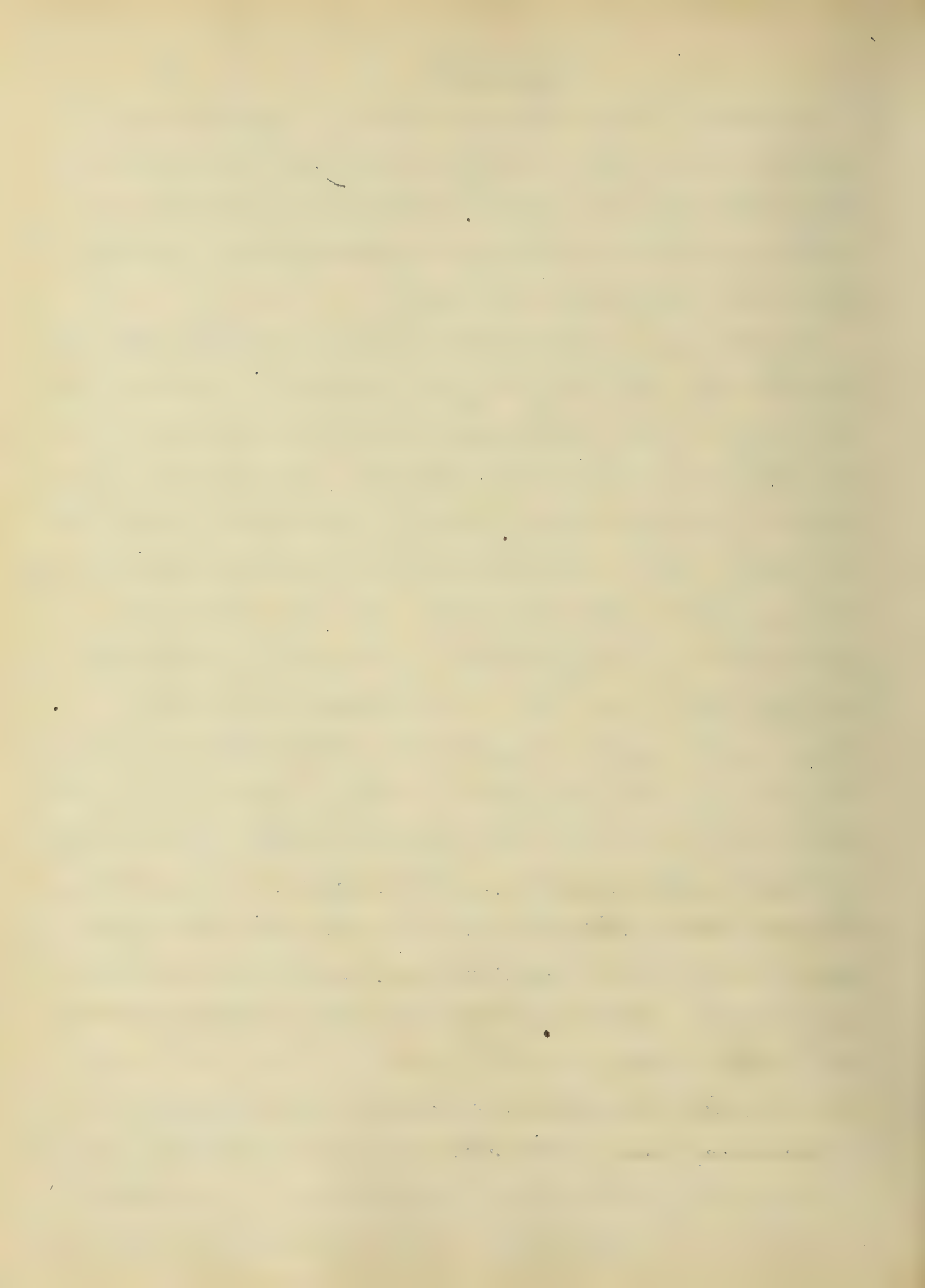


## Conclusions

In General. Perhaps the most convenient method of summarizing is to return to page 9, on which are named the three factors entering into the design of a meter, and see what conclusions can be drawn regarding them, in the light of the experiments performed.

Approach pipes and Connections. It is undoubtedly the fact that the longer the straight pipe used as an approach, the better will be the conditions for uniform measurement. On the other hand, it is as true that in practice this length of pipe will always be constricted by considerations of head loss, and space. Where head loss is no consideration the discharge pipe can be directly connected with the main by means of an elbow, allowing the former to extend up into the air. In case economy of space is the lesser consideration, a long inverted syphon may be connected to the main, so that the discharge will take place without wasting any of the head in the main. If both factors have to be carefully looked after, the installation of the meter must consist in the combination of these two plans in the most advantageous way. In Fig III the apparatus is seen to consist of an inverted syphon, which is believed by the writers to be the most practical form.

68. The apparatus should be provided with a valve in such a place that the meter flow may be controlled from a point from which the meter itself is visible. The most advantageous thing about this meter is its accessibility under all



conditions.

69 Further investigation will probably develop better plans for baffles, but, in any case, that made in the course of these experiments has amply shown them to be necessary under ordinary conditions. Fig ~~II~~ gives the details for two baffles for an 8" jet meter. The first is a steel plate baffle, with circular holes, closely spaced. It is recommended to be placed where shown in that figure, to distribute the flow, concentrated by the bend in the tube into one side of the apparatus, over the cross section of the apparatus. The second shown is of wood, with square holes. It is to be placed in the middle of the reducing apparatus to smooth, and further distribute, the flow. The size of holes shown in Fig ~~II~~ is recommended for all sizes of meter, as being that which most thoroughly serve the purpose of a baffle, while still allowing most of the debris, carried by reasonably pure water, to pass thru them. It has been thought useless to repeat the details for other sizes of apparatus in Fig ~~II~~.

70 The form of pipe used in these experiments seemed to work well, altho there is no proof that a more simple form would not be as efficient. The dimensions used are easy to standardize. The combination of tubes and baffles is easy to fit together, and may be taken apart readily for inspection and cleaning.

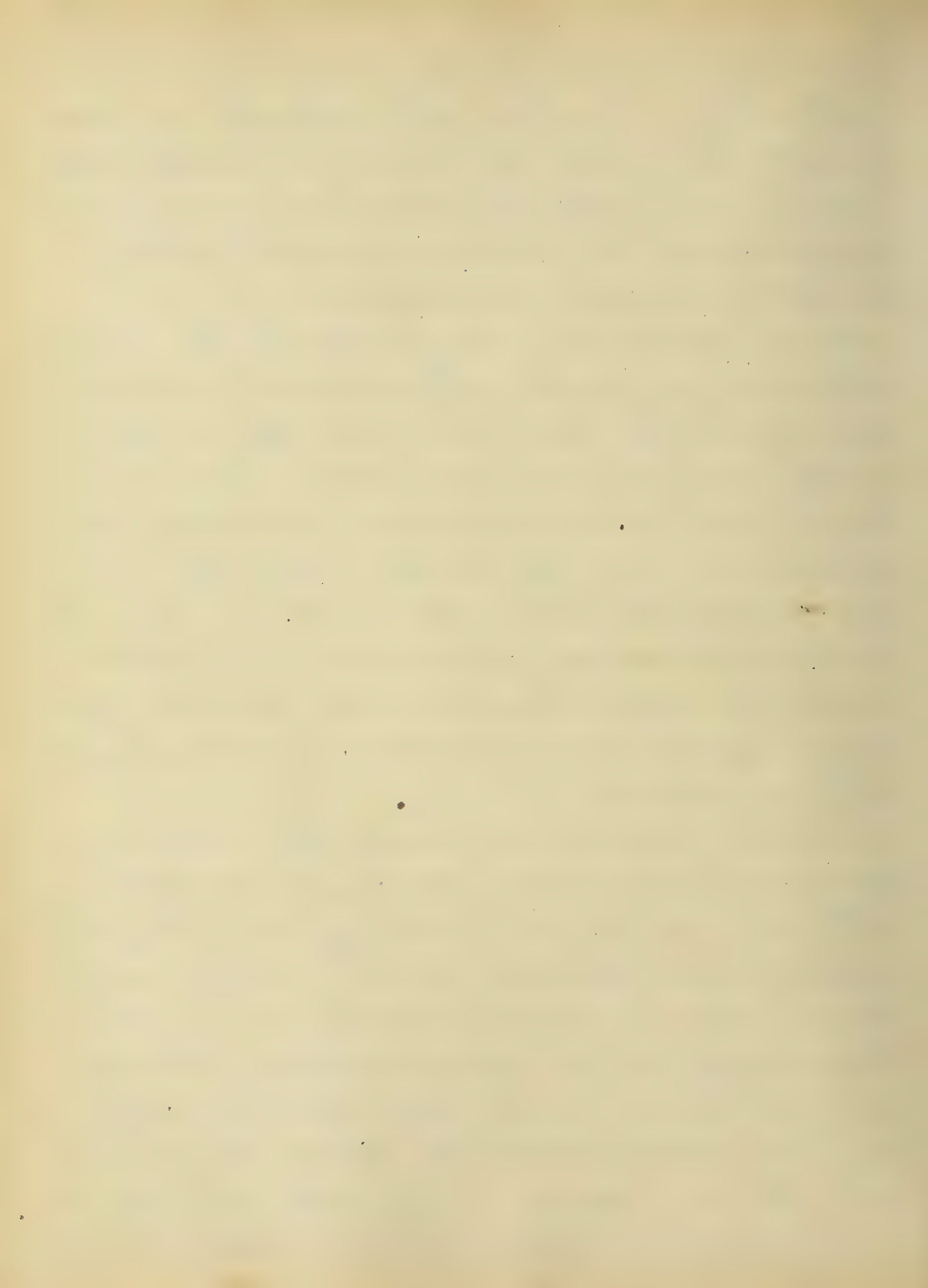
Discharge Pipes and Connections. There is little need to go over the discussion between the use of a short tube, and of an orifice. In summing up it should be said that



contraction is valuable, in so far as the pressure caused by the shape of the outside of the water column prevents the latter from breaking and foaming at the edge of the opening, and causes the filaments to rise in nearly parallel lines; these lines being continued in smooth curves, so that the top of the jet is regular.

72 This latter condition is brought about by the use of an orifice, smaller in size than the tube on which it is put. Just what the <sup>advisable</sup> upper limit of the ratio  $\frac{\text{orifice}}{\text{tube}}$  is, the writers are not prepared to state. In their experiments with 11" orifice on 12" tube, an undesirable flow condition undoubtedly was met with - while with the 10" orifice, the same condition was not at all troublesome. However, to say that the limit of the ratio lay between those sizes would be generalization without foundation. This part of the subject must be left to further investigation, and to the observation of the user of the meter.

73 The orifice ought, in the opinion of the writers, to be placed on top of a small length of cylindrical pipe. Altho nothing definite can be said against putting the orifice directly on top of the reducer, as was done in a few of the tests, this form of a meter would be much harder to duplicate than one in which the plain pipe was used. In addition, the paths of the filaments of water in a short tube must be approximately parallel, while those in a reducer, may be confused by numerous conditions, such as the slope of the reducer sides, and their length.



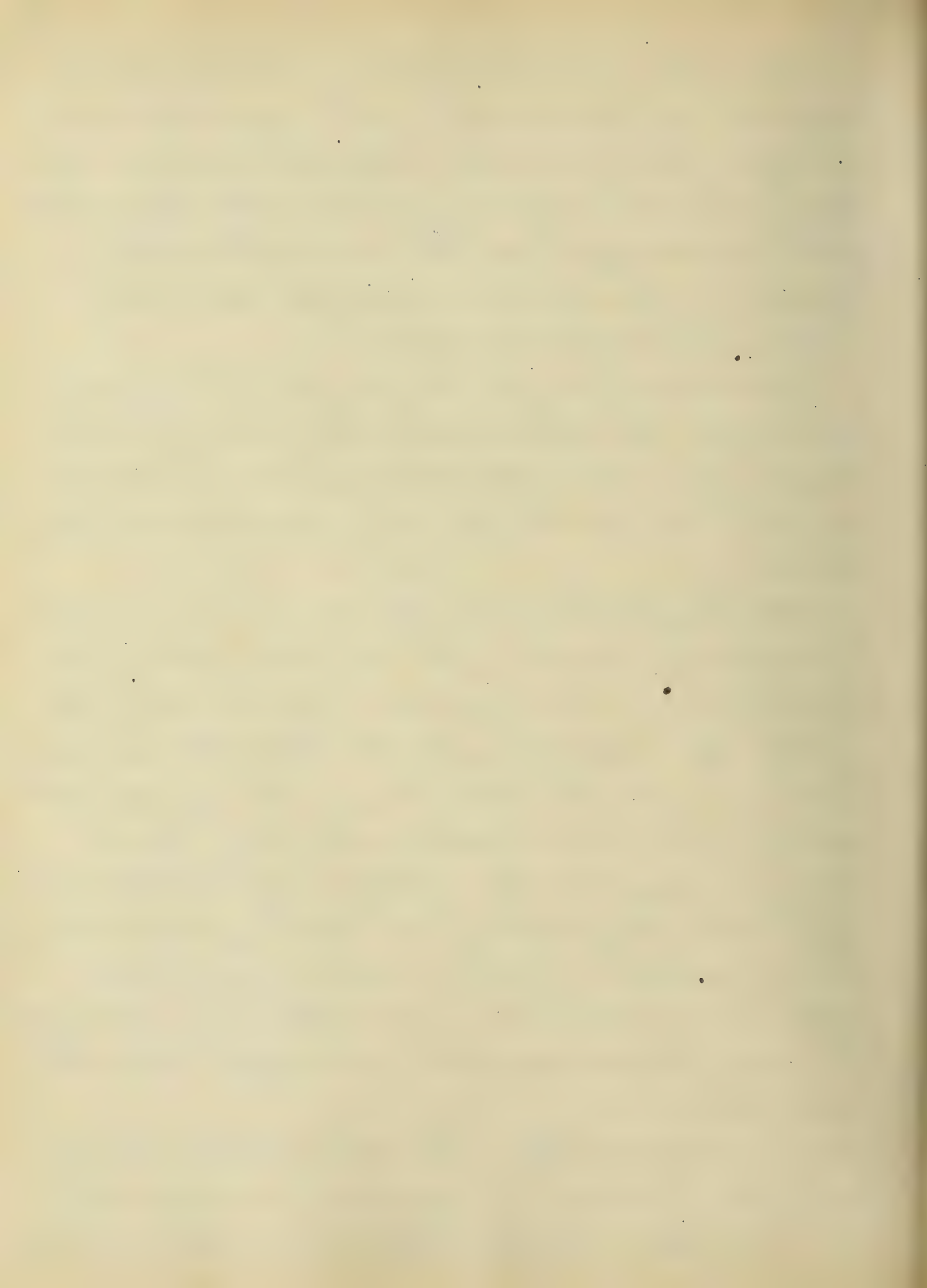
74 It would be desirable to have some standard form of orifice plate manufactured which would not call for such a clumsy connection, as does the simple plate used in this thesis. This could be done by threading the edge of the plate and screwing it into the inside of the tube, or by fastening lugs onto the outside of the tube, which could be bolted to the orifice plate.

75 The short tube may be of any length. That suggested, which equals the diameter of the pipe, is thought to be long enough to secure parallelism of flow, and, at the same time, to furnish an easily remembered standard condition.

76 The "set-up" of this whole apparatus is shown in Fig XII.

Head Measuring Apparatus. After all is done, it is useless to pretend to see advantages where there are none. The capillary tube is inconvenient, the Pitot tubes are bound to be inaccurate. The level rods are the only practical apparatus tried. Under low heads they may be read easily, and very accurately, to thousandths of feet, under high heads, when jumping and trembling would render the other methods useless, one used to doing it can average the heights of head by eye, within a very close range of accuracy. The arrangement is neat, compact, accessible and simple.

78 It is suggested, that if the discharge pipe be large, so that the head must be read very accurately, some such arrangement as the following be adopted, in place



of simple reading by eye: Mount upon the observer's rod a slider, provided with clamp, and slow motion, and fasten to this a small level telescope, provided with cross hairs. This could be slid up and down until its line of sight was tangent to the top of the jet, then, after checking the reading by observing both rod heights opposite the line of sight, and also the level bubble, clamping them in that position.

78 In a large apparatus the orifice could be, if desirable, placed below the level of the observers, so that the jet would only rise slightly above their level. The two rods could be any desired distance from the jet, altho their distances should, for convenience, be evenly related.

Other Details of the Design. By referring to Fig III, one can get a good notion of the writer's idea of a large jet meter apparatus. The main is connected to an inverted syphon, to the short arm of which is fastened the meter apparatus. The discharge takes place into a concrete pit, just large enough to contain, without restricting it; from whence it flows off thru another main. The two rods are placed on opposite sides of the discharge pit.

Size of Apparatus The question at once comes up, "How large can it be made?" In reply it might be said that the maximum <sup>size of pipe</sup> size would be determined by the ability to gage it, and obtain its coefficients. However the difficulty of erection and management would increase rapidly with increased size, and it is not likely that a pipe



larger than the largest water supply size could be used to advantage.

81 However, there are two factors which really regulate the size to be used (1) the available head, and (2) the jet head desired, or thought practicable. In the first place, a much larger head is required to cause a small pipe to discharge, than is required to cause a large pipe to discharge the same quantity. If the available head is unlimited a small pipe may be used, thus securing some economy of space, while if the head is small, a large pipe must be used, which will discharge the same amount under a lower head. Then, in the second case, a high jet is not desirable. The most desirable height is that when the flow has just barely reached that equilibrium condition represented by the horizontal lines in the coefficient curves. Any further increase in head simply increases the unsteadiness of the flow, and it is better, if the discharge head becomes much greater, to increase the size of the pipe.

82 The ratio,  $\frac{\text{orifice}}{\text{tube}}$ , should be the keynote for further experiment. At present, the best suggestion which can be offered is to make the approach tube of the same size as the main, and cap this tube with the desired size of orifice.

83. On the following page is given a table which shows the most efficient discharge, in gallons per day, from various sized meters. These are based on the principle stated in the foregoing paragraph, and, while but rough approximations, serve to show the range of the meter.



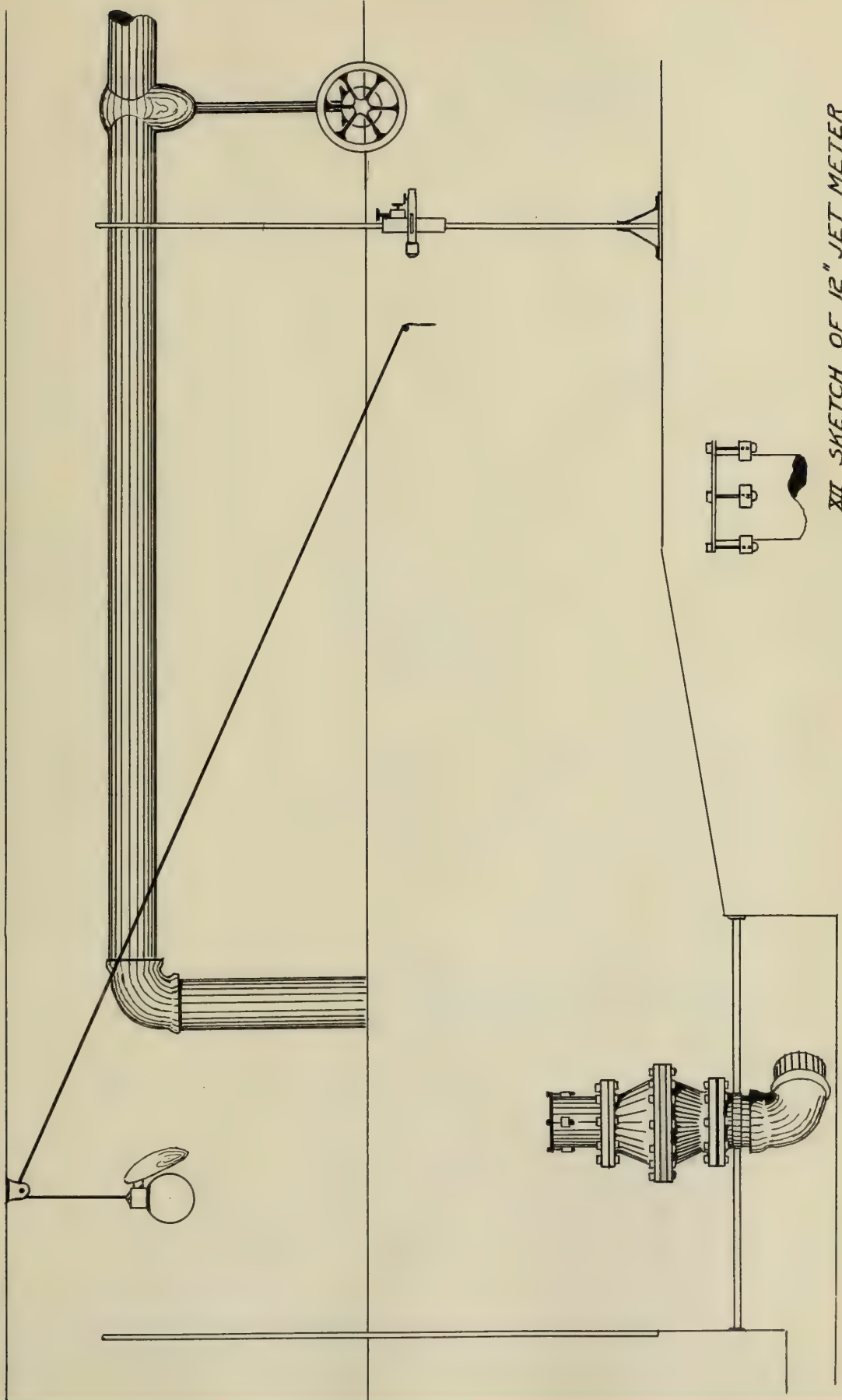
Size Orifice	4"	6"	8"	10"	12"	16"	20"	24"
Size tube	8"	8"	12"	12"	16"	20"	24"	30"
Minimum Head	1 ft	1 ft	1.7 ft	1.7 ft	1.7 ft	2 ft	2 ft	2 ft
Disch. gal/day	300,000	700,000	1,600,000	2,400,000	3,700,000	7,000,000	11,000,000	18,000,000

Availability. The jet meter, as described herein, is available wherever the weir or vertical orifice would be, up to certain practical limits of size, before mentioned, i.e. wherever it is possible to change all the pressure head into velocity head. Needless to say, where static pressure must be maintained, the vertical jet would be useless.

85 Numberless instances could be given of places where the jet meter could be available. Pumping tests, calibration stations at the heads of pipe lines, gaging of small streams - all could employ the jet meter. It is of remarkably cheap construction, is very simple, compact, adaptable to widely varying circumstances, convenient for inspection and repair.

86 In such a preliminary investigation as has been undertaken in this thesis, accurate and voluminous results cannot be expected. If the writers have been able to interest their readers in what they consider a valuable engineering instrument in embryo, they will be well satisfied.





XII SKETCH OF 12" JET METER AND ACCESSORIES.





TABLE No. 3  
4 IN. ORIFICE

For weir,  $Q = c \frac{3}{2} b \sqrt{2g} h^{\frac{3}{2}}$ ; for jet,  $Q = C a \sqrt{2g} H^{\frac{5}{2}}$ ;  $b = 3$ ;  $a = .0873$ ;  $C = 22.92 + c \cdot h^{\frac{1}{2}} / H^{\frac{1}{2}}$  (c from Meriman)

Weir				Jet				Weir				Jet			
Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.
Set 1.				12"-8" reducer				Set 2.				8" short pipe			
		Orifice on	[zero = 1.547]						Orifice on		[zero = 1.547]				[zero = 6.88]
1.696		7.88		7.88				1.753				11.28			
1.696		7.87		7.87				1.752				11.26			
1.696		7.87		7.87				1.752				11.28			
1.697		7.88		7.88				1.751				11.29			
1.696	1.696	.149	.638	7.88	7.88	1.81	.625	1.752	1.752	.205	.629	11.26	11.27	4.44	.635
1.708				8.29				1.748				11.01			
1.708				8.28				1.748				11.02			
1.708				8.31				1.748				11.00		4.18	.636
1.708				8.30				1.748				10.99	11.01		
1.708	1.708	.161	.636	8.31	8.30	2.23	.630	1.748	1.748	.201	.630	10.68			
1.721				8.87				1.743				10.65			
1.721				8.87				1.743				10.65			
1.721				8.88				1.742				10.64			
1.721				8.87				1.741				10.62			
1.721	1.721	.174	.634	8.87	8.87	2.80	.631	1.741	1.742	.195	.631	10.62	10.65	3.82	.638
1.735				9.61				1.738				10.40			
1.734				9.60				1.737				10.42			
1.733				9.57				1.737				10.43			
1.734				9.56				1.738				10.43			
1.734	1.734	.187	.632	9.55	9.58	3.51	.626	1.739	1.738	.191	.631	10.44	10.42	3.59	.637
1.748				10.43				1.735				10.22			
1.748				10.42				1.735				10.21			
1.748				10.40				1.735				10.25			
1.748				10.37				1.735				10.25			
1.747	1.748	.211	.628	10.40	10.40	4.33	.671	1.736	1.735	.188	.632	10.26	10.24	3.41	.640
1.762				11.35				1.732				10.05			
1.762				11.37				1.732				10.06			
1.762				11.37				1.731				10.08			
1.762				11.37				1.732				10.08			
1.762	1.762	.215	.628	11.37	11.37	5.30	.623	1.732	1.732	.185	.632	10.10	10.07	3.24	.640

(cont. TABLE No. 4)



TABLE No. 2  
8 IN. SHORT PIPE  
Actual diameter of pipe = 8.4 ins.

Weir				Jet				Weir				Jet			
Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.
Set 4 - 2 baffles															
1.751				1.20				1.394				.110			
1.750				1.15				1.391				.110			
1.745				1.14				1.391				.110			
1.746				1.18				1.390				.110			
1.750				1.14				1.390				.110			
1.748				1.12				1.390				.110			
1.750	1.749	.433	.611	1.16	1.16	1.16	.897		1.391	.075	.660		.110	.110	.226
1.674				.73											
1.675				.73											
1.676				.74											
1.677				.75											
1.677				.75											
1.678				.73											
1.678	1.676	.360	.615	.71	.73	.73	.863								
1.594				.45											
1.595				.44											
1.594				.43											
1.592				.44											
1.591				.43											
1.590	1.593	.277	.621	.44	.44	.44	.762								
1.504				.263											
1.505				.264											
1.505				.268											
1.506				.265											
1.505				.265											
1.505	1.505	.189	.631	.267	.265	.265	.559								
1.439				.175											
1.442				.174											
1.438				.174											
1.438				.175											
1.439				.175											
1.439	1.439	.123	.646	.175	.175	.175	.371								

For weir,  $Q = c \frac{2}{3} b \sqrt{2g} h^{\frac{3}{2}}$

For jet,  $Q = C a \sqrt{2gH}$

$b = 3'$   
 $a = .36''$

$C = c \cdot 5.56 \frac{H^{\frac{3}{2}}}{H^{\frac{3}{2}}}$

Values of  $c$  taken from Merriman's "Hydraulics"



Discharge from plotted curve.

For jet,  $C = Q \div \sqrt{2gH}$

[illegible]

TABLE No. 5  
4 IN. ORIFICE ON 8 IN. PIPE

For pit, 1-ft. rise = 179.2 cu. ft. For jet,  $C = Q / 7.4\sqrt{H}$

Pit		Time (sec.)	Disch. (cuft/sec.)	Jet			[zero = 6.83]	Pit		Time (sec.)	Disch. (cuft/sec.)	Jet			[zero = 6.83]
Gage	Rise			Obs.	Mean	Head		Coef.	Gage			Rise	Obs.	Mean	
Set 3		-													
.187				10.93 10.90 10.90 10.88 10.88 10.87				(.130)							
				10.86 10.87 10.88				1.964	1.834	898	.366			7.50	.638
								.247						7.22 7.21 7.21 7.21 7.22 7.22 7.23 7.23	
1.907	1.720 .005 = leakage 1.725	340	.910		10.88	4.05	.646	1.822	1.575	1039	.272			7.22	.622
.329				9.69 9.65 9.65 9.67 9.66 9.65 9.65 9.64 9.61											
1.926	1.597	380	.753		9.61	2.82	.641	.404							
.230				8.80 8.78 8.79 8.79 8.78 8.77 8.76 8.76 8.76											
1.998	1.768	510	.621		8.76	1.95	.635	1.877	1.473	549	.481			7.97	.643
.130								.176							
				7.51 7.51 7.51 7.51 7.50											
								1.891	1.715	607	.507				

(cont. Table No. 6)



TABLE No. 6

4 IN. ORIFICE ON 8 IN. PIPE

For pit, 1-ft. rise = 179.2 cu. ft.

For jet,  $C = Q/1.7H^{\frac{1}{2}}$

[illegible]











TABLE No. 9  
6 IN. ORIFICE ON 12 IN. PIPE

For weir,  $Q = c\sqrt{2gh}h^{\frac{3}{2}}$ ; for jet,  $Q = C\sqrt{2gH}H$ ;  $C = 10.18 \times c \cdot h^{\frac{1}{2}}/H^{\frac{1}{2}}$

Weir [zero=1547]				Jet [zero=683]				Weir				Jet			
Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.
Set 2 (cont.)															
1.872				9.86				1.825				8.75			
1.870								1.825				8.77			
1.872								1.825				8.72			
1.871								1.825				8.78			
1.870								1.825				8.76			
1.874								1.825				8.74			
1.873								1.825				8.78			
1.872								1.825				8.75			
1.870								1.825				8.73			
1.870		.324	.618	9.86				1.825	1.825	.278	.621	8.75	8.75	1.92	.668
1.870	1.871				9.86	3.01	.670	1.812				8.48			
1.854								1.811				8.48			
1.854								1.811				8.47			
1.853								1.811				8.47			
1.853								1.810	1.811	.264	.622	8.49	8.48	1.65	.668
1.853															
1.854								1.790				8.05			
1.853								1.791				8.05			
1.855								1.791				8.04			
1.854								1.791				8.04			
1.855								1.791				8.04			
1.841		.307	.619	9.43					1.791	.244	.625		8.04	1.21	.697
1.842															
1.841															
1.843															
1.842															
1.842															
1.843															
1.841															
1.841		.295	.619	9.09					1.791						
1.842	1.842				9.11	2.28	.669								



TABLE NO. 10  
6 IN. ORIFICE  
ON 8 IN. PIPE.

For pit 1 ft. rise = 179.2 cu. ft. For jet  $C = Q/\sqrt{1.55 H} \frac{1}{2}$

Pit		Time (Sec)	Disch (cu ft/sec)	Jet		[zero = 6.83]		Pit		Time (Sec)	Disch (cu ft/sec)	Jet		Jet	
Gage	Rise			Obs.	Mean	Head	Coef.	Gage	Rise			Obs.	Mean	Head	Coef.
<u>Set 3.</u>															
.065				7.19 7.16 7.17 7.18 7.20 7.22 7.22 7.22				.148				7.78 7.73 7.70 7.69 7.71 7.71 7.72 7.72 7.73 7.74 7.74 7.74 7.73 7.74 7.73 7.73			
1.862	1.797	529	.609		7.20	.37	.635								
.194				7.58 7.52 7.53 7.54 7.56											
1.850	1.656	326	.910		7.55	.72	.682	1.852	1.804	327	.989		7.73	.90	.662
.033				8.82 8.80 8.83 8.88				.155				8.87 8.81 8.69 8.65 8.62 8.64 8.69 8.71 8.69 8.71 8.70			
1.916	1.883	217	1.556		8.83	2.00	.678								
.122				10.48 10.18 10.10 10.14 10.10											
1.887	1.765	161	1.965		10.20	3.37	.680	2.059	1.904	232	1.470		8.71	1.88	.680
<u>Set 4.</u>								.127							
.008				11.24 11.03 10.74 10.50 10.25 9.95 9.80 9.58								9.85 9.62 9.70 9.75 9.75 9.80 9.65 9.70 9.60			
2.103	2.095	192	1.956		10.27	3.44	.681	2.037	1.910	189	1.812		9.71	2.88	.678
										(cont. Table No. 11)					



TABLE No. 11  
6 IN. ORIFICE ON 8 IN. PIPE

For jet  $C = Q/\sqrt{5}H^{1/2}$ .

For pit. 1 ft rise = 179.2 cu. ft.

Pit		Time (Sec)	Disch. (cu ft/sec)	Jet [zero = 6.83]			Pit		Time (Sec)	Disch. (Cu ft/sec)	Jet		
Gage	Rise			Obs	Mean	Head	Coef.	Gage			Rise	Obs	Mean
Set 4.		(cont.)						Set 5.					
.006				11.10 11.32 11.35				.000					
2.582	2.583	194	2.387	11.50	11.32	4.42	.715						
.133				10.85 10.55 10.40 10.37 10.34 10.20 10.25									
2.069	1.936	171	2.027	10.25	10.40	3.57	.681	1.921	1.921	819	.420	7.09	.523
.159				10.25				.000					
				7.39 7.38 7.38 7.38 7.38 7.39 7.39 7.38 7.39 7.38 7.39 7.40 7.40 7.40 7.39 7.40 7.40 7.41									
								1.921	1.921	824	.418	7.09	.520
								.000					
										</			

(cont. Table No. 12)



TABLE No. 12.  
6 IN. ORIFICE ON 8 IN. PIPE.  
For pit 1 ft. rise = 179.2 cu. ft. For jet  $C = Q/4515H^{1/2}$

Pit		Time (Sec)	Disch (cu ft/sec)	Jet [zero = 6.83]			Pit		Time (Sec.)	Disch (cu ft/sec)	Jet [zero = 6.83]			
Gage	Rise			Obs.	Mean	Head	Coef.	Gage			Rise	Obs.	Mean	Head
Set 5.														
.000				7.31 7.33 7.34 7.34 7.35 7.35 7.36 7.36				.000						
<u>1.921</u>	<u>1.921</u>	481	.717		7.34	.51	.637	<u>1.485</u>	<u>1.485</u>	502	.530	7.14	.31	.544
.000				7.19 7.19 7.20 7.20 7.20 7.20 7.20 7.20 7.20				.000						
<u>1.921</u>	<u>1.921</u>	603	.571		7.20	.37	.596	<u>1.514</u>	<u>1.514</u>	335	.840	7.43	.60	.689
.000				7.13 7.14 7.14 7.14 7.13 7.13 7.13 7.13 7.13										
<u>1.921</u>	<u>1.921</u>	710	.485		7.13	.30	.562	<u>2.060</u>	<u>2.060</u>	278	1.328	8.33	1.50	.688
Set 6.														
.000				8.00 7.97 7.95 7.95 7.95 7.95				.000						
<u>1.488</u>	<u>1.488</u>	235	1.134		7.96	1.13	.678	<u>1.654</u>	<u>1.654</u>	688	.431	7.07	.24	.558



Table No. 13.

## 8 IN. ORIFICE ON 12 IN. PIPE.

For weir,  $Q = C \frac{8}{15} b \sqrt{g} h^{3/2}$  ; for jet,  $Q = C A \sqrt{2gH}$  ,  $C = 5.73 \times C_d \sqrt{H}$

Weir [zero=1.596]				Jet [zero=6.92]				Weir [zero=1.596]				Jet [zero=6.92]			
Obs.	Mean	h	c.	Obs.	Mean	H.	C.	Obs.	Mean	h	c.	Obs.	Mean	H	C.
1.848				7.34				1.956				8.24			
1.850				7.37				1.954				8.20			
1.853				7.37				1.953				8.19		1.41	.630
1.855				7.37				2.007		.356	.616	8.90			
1.856				7.37				2.008				8.94			
1.854				7.38				2.008				8.95			
1.855				7.38				2.010				8.93			
1.855				7.38				2.007				8.90			
1.856				7.38				2.009				8.93			
1.883	1.854	.258	.623	7.51	7.37	.58	.614	2.007				8.91			
1.878				7.51				2.007				8.91			
1.877				7.51				2.008		.412	.612	8.93		2.13	.636
1.876				7.51				2.046				9.51			
1.876				7.50				2.047				9.51			
1.875				7.50				2.047				9.53			
1.875				7.50				2.048				9.52			
1.875				7.51				2.047				9.51			
1.875				7.51				2.048				9.53			
1.875	1.877	.281	.621	7.51	7.51	.72	.625	2.051				9.54			
1.909				7.76				2.050				9.58			
1.909				7.77				2.050		.452	.610	9.58			
1.910				7.77				2.050				9.59		2.75	.640
1.910				7.76				2.106				10.70			
1.909				7.75				2.104				10.72			
1.909				7.74				2.103				10.70			
1.908				7.74				2.106				10.73			
1.908				7.75				2.110				10.74			
1.909				7.73				2.107				10.75			
1.909	1.909	.313	.618	7.74	7.75	.96	.633	2.108				10.74			
1.945				8.13				2.112				10.82			
1.948				8.16				2.114				10.91			
1.951				8.19				2.113		.512	.608	10.92			
1.952				8.19				1.809				7.18			
1.953				8.22				1.808				7.18			
1.953				8.22				1.808				7.17			
1.956				8.22				1.806				7.17			
1.956				8.22				1.805		.211	.629	7.17			
								1.804				7.18		.39	.546



TABLE NO. 14

8 IN ORIFICE ON 12 IN PIPE.

2 BAFFLES.

For weir,  $Q = c \frac{3}{2} b \sqrt{2g} \cdot h^{\frac{3}{2}}$ ; for jet,  $Q = C a \sqrt{2g} H$ ,  $C = 5.73 \times c \cdot h^{\frac{1}{2}} / H^{\frac{1}{2}}$ 

Weir [zero=1.596]				Jet [zero=6.92]				Weir [zero=1.596]				Jet [zero=6.92]			
Obs.	Mean	h	c.	Obs.	Mean	H.	C.	Obs.	Mean	h	c.	Obs.	Mean	H.	C.
1.810				7.31				1.940				8.18			
1.812				7.32				1.940				8.17			
1.812				7.32				1.940				8.18			
1.814				7.32				1.942				8.18			
1.814				7.33				1.940	1.940	.344	.616	8.19	8.18	1.26	.636
1.814				7.33											
1.814				7.33				1.985				8.70			
1.814				7.34				1.986				8.71			
1.814				7.33				1.984				8.71			
1.814				7.33				1.985				8.70			
1.814	1.813	.217	.628	7.33	7.33	.41	.567	1.985				8.71			
1.852				7.49				1.985				8.71			
1.850				7.48				1.984				8.69			
1.848				7.47				1.984				8.71			
1.848				7.47				1.984				8.69			
1.848				7.47				1.984	1.985	.389	.614	8.69	8.70	1.78	.641
1.848				7.47											
1.848				7.48											
1.848				7.47											
1.848				7.47											
1.848	1.849	.253	.624	7.48	7.48	.56	.609								
1.900				7.80				2.020				9.20			
1.900				7.81				2.020				9.20			
1.901				7.82				2.021				9.23			
1.902				7.82				2.022				9.21			
1.903				7.83				2.022				9.21			
1.904				7.84				2.023				9.24			
1.905				7.84											
1.906				7.86				2.060				9.91			
1.907				7.87				2.058				9.89			
1.909	1.904	.308	.619	7.88	7.84	.92	.632	2.057				9.84			
1.941								2.056				9.82			
1.940				8.19				2.056				9.82			
1.939				8.19				2.055				9.82			
1.940				8.18				2.056				9.84			
1.940				8.17				2.057				9.87			
1.940				8.18				2.056	2.057	.461	.610	9.87	9.85	2.93	.638



TABLE No. 15

8 IN. ORIFICE ON 12 IN. PIPE.

2 BAFFLES.

For weir,  $Q = c \frac{8}{15} b \sqrt{2g} h^{\frac{3}{2}}$ ; for jet,  $Q = C a \sqrt{2g} H$ ,  $C = 5.73 x c h^{\frac{3}{4}} / H^{\frac{1}{2}}$ 

Weir [zero = 1.596]				Jet [zero = 6.92]				Weir [zero = 1.596]				Jet [zero = 6.92]			
Obs.	Mean	h	c.	Obs.	Mean	H	C.	Obs.	Mean	h.	c.	Obs.	Mean	H.	C.
2.082				10.34				1.868				7.56			
2.085				10.40				1.865				7.56			
2.087				10.42				1.865				7.57			
2.087				10.40				1.865				7.56			
2.088				10.42				1.865	1.866	.270	.622	7.56	7.56	.64	.625
2.087				10.42											
2.086				10.40											
2.085				10.39				1.957				8.40			
2.085				10.39				1.959				8.40			
2.084	2.086	.490	.609	10.38	10.40	3.48	.642	1.959				8.41			
								1.960	1.959	.363	.615	8.40	8.40	1.48	.635
2.103				10.76				1.960							
2.103				10.74											
2.103				10.76				2.003				9.01			
2.104				10.76				2.005				9.04			
2.104				10.77				2.006				9.02			
2.106				10.78				2.007				9.04			
2.105				10.84				2.007	2.006	.410	.613	9.02	9.03	2.11	.635
2.109				10.85											
2.109				10.86											
2.109	2.106	.510	.608	10.86	10.80	3.88	.644								
								2.049				9.73			
2.132				11.38				2.050				9.72			
2.130				11.36				2.050				9.71			
2.131				11.38				2.050	2.050	.454	.610	9.71	9.72	2.80	.639
2.130				11.39											
2.131				11.39				2.125				11.25			
2.131				11.36				2.123				11.26			
2.130				11.36				2.123				11.24			
2.130				11.40				2.125				11.26			
2.130				11.37				2.123	2.124	.528	.607	11.27	11.24	4.34	.642
2.129				11.35											
2.131	2.130	.534	.607	11.36	11.37	4.45	.643								



TABLE No. 16  
10 IN. ORIFICE ON 12 IN. PIPE.  
1 BAFFLE.

For weir,  $Q = c \frac{2}{3} b \sqrt{2g} \cdot h^{\frac{3}{2}}$  ; for jet,  $Q = C a \sqrt{2gH}$  ;  $C = 3.67 \cdot c \cdot h^{\frac{3}{2}} / H^{\frac{3}{2}}$

Weir [zero = 1.596]				Jet [zero = 6.79]				Weir [zero = 1.596]				Jet [zero = 6.79]			
Obs.	Mean	h	c.	Obs.	Mean	H	C.	Obs.	Mean	h	c.	Obs.	Mean	H	C.
1.924				7.29				2.091				8.08			
1.925				7.29				2.091				8.09			
1.925				7.29				2.093				8.09			
1.926				7.30				2.093				8.09			
1.929				7.31				2.094	2.092	4.96	.608	8.09	8.07	1.28	.691
1.930				7.31				2.145				8.49			
1.930				7.31				2.143				8.50			
1.932				7.32				2.145				8.51			
1.932				7.33				2.145				8.50			
1.933	1.929	.333	.617	7.33	7.31	.52	.604	2.146				8.50			
								2.145				8.49			
1.976				7.46				2.144				8.50			
1.976				7.46				2.143				8.50			
1.976				7.46				2.143				8.50			
1.977				7.47				2.143	2.144	.548	.607	8.49	8.50	1.71	.691
1.977				7.47				2.195				9.01			
1.977				7.47				2.196				9.01			
1.975				7.46				2.197				8.99			
1.975				7.45				2.194				9.00			
1.974				7.45				2.195				9.01			
1.975	1.979	.383	.614	7.45	7.46	.67	.652	2.196				9.01			
								2.196				9.02			
2.037				7.72				2.198				9.02			
2.038				7.72				2.198				9.00			
2.037				7.73				2.198				9.00			
2.038				7.72				2.200	2.196	.600	.605	9.06	9.01	2.22	.693
2.039				7.71								9.06			
2.037				7.73				1.929				7.31			
2.035				7.71				1.929				7.30			
2.033				7.71				1.928				7.31			
2.032				7.71				1.927				7.31			
2.032	2.036	.440	.611	7.69	7.72	.93	.678	1.925				7.31			
2.092				8.04				1.926				7.31			
2.090				8.04				1.924				7.29			
2.090				8.05				1.925				7.29			
2.090				8.06				1.924				7.30			
2.091				8.07				1.923	1.926	.330	.617	7.30	7.30	.51	.601



TABLE No. 17

10 IN. ORIFICE ON 12 IN. PIPE.

For weir,  $Q = c \cdot 3.6 \sqrt{2g} h^{3/2}$ ; for jet,  $Q = C \sqrt{2g} H^{3/2}$ ;  $C = c \cdot 3.67 \cdot h^{1/4} / H^{1/4}$

Weir [zero = 1.596]				Jet [zero = 6.79]				Weir [zero = 1.596]				Jet [zero = 6.79]			
Obs.	Mean	h	c	Obs.	Mean	H	C.	Obs.	Mean	h	c	Obs.	Mean	H	C.
1.843				7.24				2.039				7.85			
1.845				7.24				2.032				7.85			
1.847				7.24				2.068				8.01			
1.847				7.24				2.068				8.01			
1.849				7.24				2.068				8.01			
1.849				7.25				2.067				8.01			
1.850				7.25				2.104				8.01			
1.850				7.25				2.105				8.27			
1.851				7.25				2.106				8.30			
1.851				7.25				2.107				8.30			
1.852				7.26				2.107				8.30			
1.853				7.27				2.107				8.30			
1.853				7.27				2.148				8.63			
1.853				7.27				2.150				8.61			
1.854				7.27				2.178				8.62			
1.901	1.850	.254	.624	7.37	7.25	.33	.511	2.151				8.62			
1.902				7.37				2.151				8.62			
1.903				7.37				2.172				8.63			
1.903				7.37				2.173				8.82			
1.903				7.37				2.169				8.81			
1.903	1.902	.306	.619	7.37	7.37	.45	.585	2.169				8.78			
1.927				7.43				2.168				8.76			
1.927				7.43				2.199				9.09			
1.926				7.43				2.178				9.05			
1.925				7.42				2.196				9.09			
1.923				7.41				2.192				9.01			
1.964	1.926	.330	.617	7.54	7.42	.50	.607	2.192				9.01			
1.964				7.55				2.193				9.02			
1.967				7.56				2.194				9.02			
1.967				7.56				2.194				9.02			
1.968	1.966	.370	.615	7.56	7.55	.63	.640	2.195				9.02			
1.998				7.66				2.195				9.02			
1.998				7.68				2.195				9.02			
1.999				7.66				2.195				9.02			
1.999				7.68				2.195				9.02			
2.000	1.999	.403	.613	7.68	7.67	.75	.665	2.195				9.02			
2.040				7.68				2.195				9.02			
2.040				7.85				2.195				9.02			
2.040				7.85				2.195				9.02			
2.040				7.85				2.195				9.02			



TABLE No 18.  
11 IN. ORIFICE ON 12 IN PIPE.

For weir,  $Q = c \frac{2}{3} b \sqrt{2g} h^{\frac{3}{2}}$ ; for jet,  $Q = C a \sqrt{2g} H$ ;  $C = 3.03 \times c \cdot h^{\frac{1}{2}} / H^{\frac{1}{2}}$

Weir [zero 1.596]				Jet [zero=6.92]				Weir [zero=1.596]				Jet [zero=6.92]			
Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.	Obs.	Mean	Head	Coef.
1.891				7.26				2.100				7.77			
1.894				7.27				2.102				7.78			
1.895				7.27				2.103				7.79			
1.896				7.27				2.103				7.79			
1.895	1.894	.298	.619	7.27	7.27	.35	.517	2.105	2.103	.507	.608	7.80	7.79	.87	.714
1.936				7.33				2.131				7.89			
1.937				7.34				2.132				7.90			
1.937				7.34				2.133				7.91			
1.937				7.34				2.133				7.91			
1.937	1.937	.341	.617	7.34	7.34	.42	.576	2.133	2.132	.536	.607	7.91	7.90	.98	.729
1.967				7.41				2.161				8.01			
1.968				7.41				2.161				8.01			
1.968				7.41				2.161				8.02			
1.968				7.41				2.164				8.02			
1.968	1.968	.372	.615	7.41	7.41	.49	.604	2.161	2.162	.566	.606	8.05	8.02	1.10	.745
2.001				7.50				2.200				8.24			
2.003				7.51				2.200				8.24			
2.003				7.51				2.196				8.24			
2.000				7.51				2.201				8.24			
2.001	2.002	.406	.613	7.51	7.51	.59	.626	2.202	2.200	.604	.605	8.25	8.25	1.32	.748
2.043				7.60											
2.042				7.60											
2.042				7.60											
2.042				7.60											
2.042	2.042	.446	.611	7.60	7.60	.68	.669	.788	.722	1.49	.869		7.10	.18	.486
2.076				7.68				1.510							
2.078				7.69				1.119	.822	90	1.64		7.19	.27	.500
2.078				7.69				1.941							
2.076				7.69				1.108	1.087	86	2.27		7.28	.36	.600
2.075	2.077	.481	.609	7.68	7.69	.77	.701	2.195							
				7.68				1.156	1.040	64	2.91		7.37	.45	.690
								2.196							

TABLE No. 19  
12 IN. SHORT TUBE.

Pit				Time (Sec)		Disch. (cu.ft./sec)		Jet		zero=6.92	
Gage	Rise							Obs.	Head	Coef.	
.788											
1.510	.722			149		.869		7.10	.18	.486	
1.119	.822			90		1.64		7.19	.27	.500	
1.941											
1.108	1.087			86		2.27		7.28	.36	.600	
2.195											
1.156	1.040			64		2.91		7.37	.45	.690	
2.196											

$$C = 2.55 \times c \cdot h^{\frac{1}{2}} / H^{\frac{1}{2}}$$



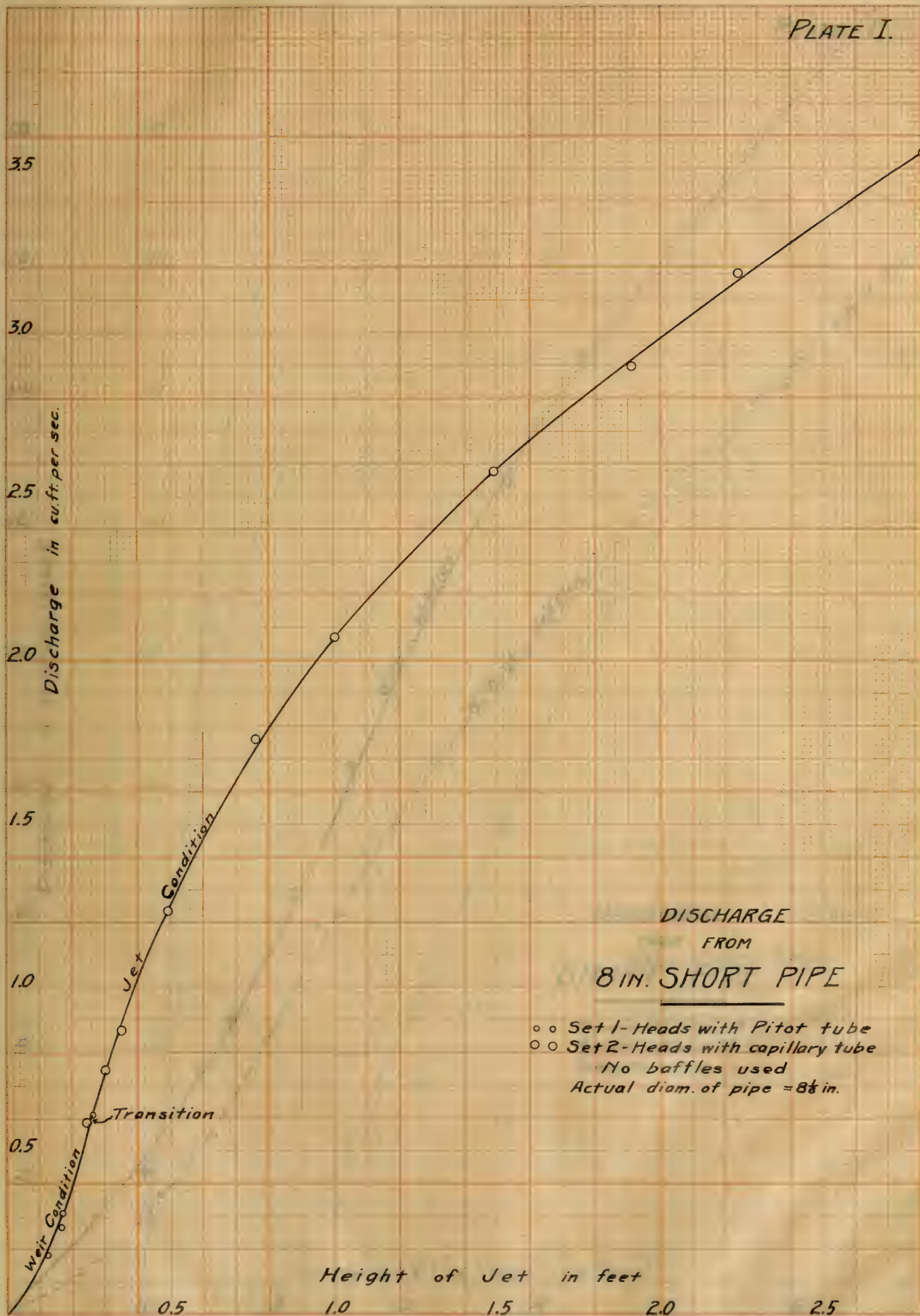


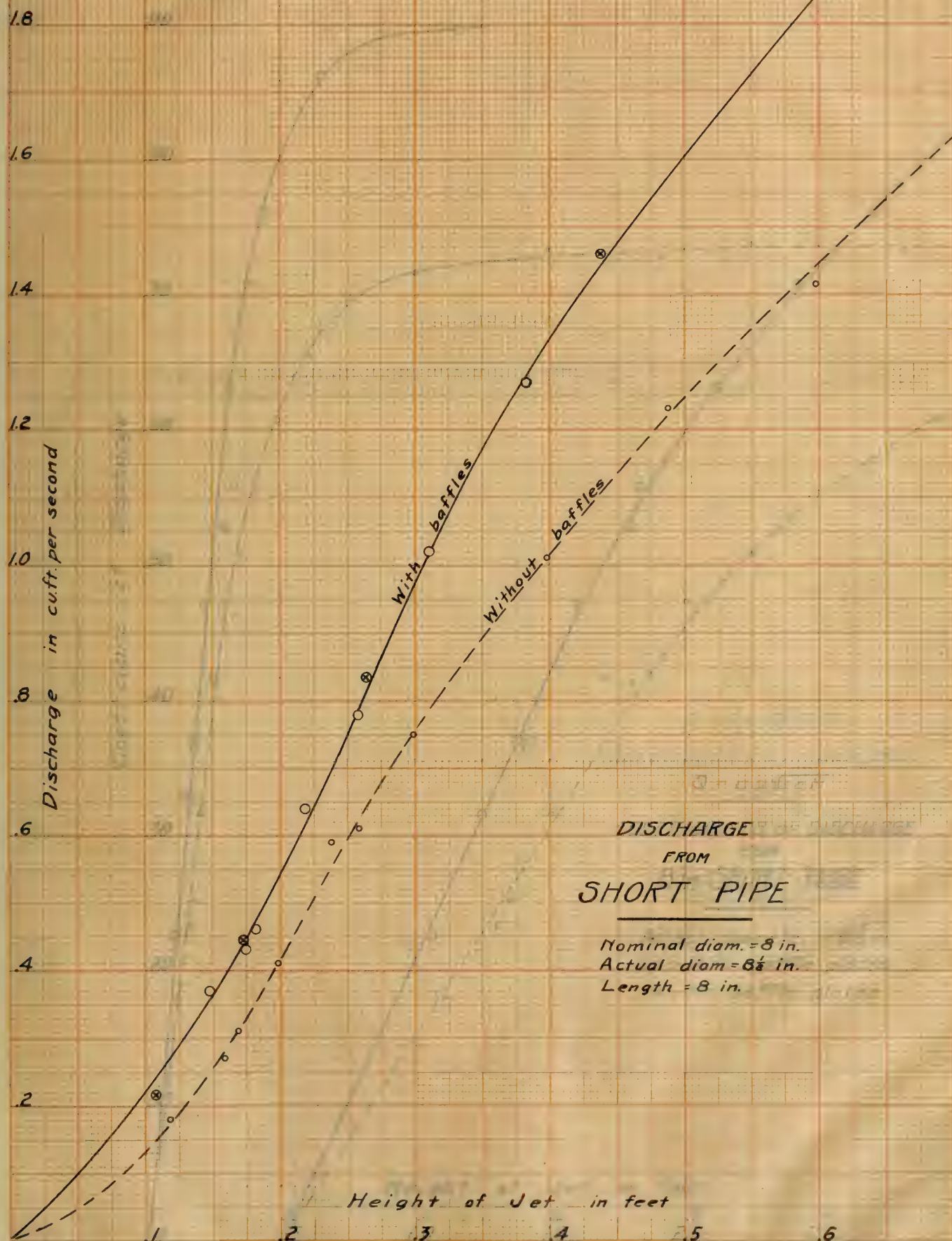
PLATE I



8m SHORT PIPE

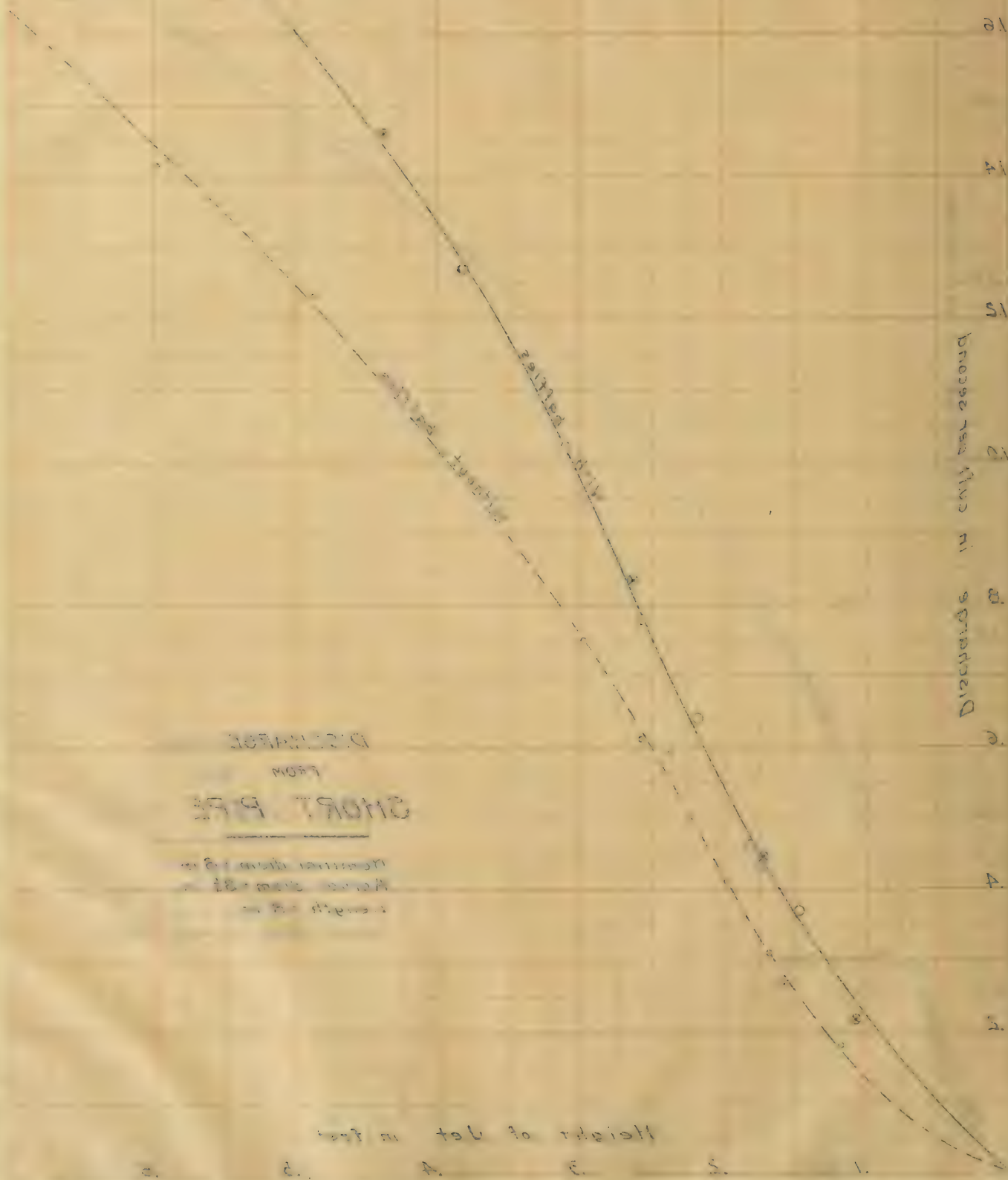
Actual diam. of pipe = 8 in.  
 The bottles used  
 20 Set-Heads with capillary tube  
 10 Set-Heads with Pitot tube

W. SCHMIDT  
 1904



DISCHARGE  
FROM  
SHORT PIPE

Nominal diam. = 8 in.  
Actual diam. =  $8\frac{1}{2}$  in.  
Length = 8 in.



SHORT PIPE  
FROM  
D. C. 1875

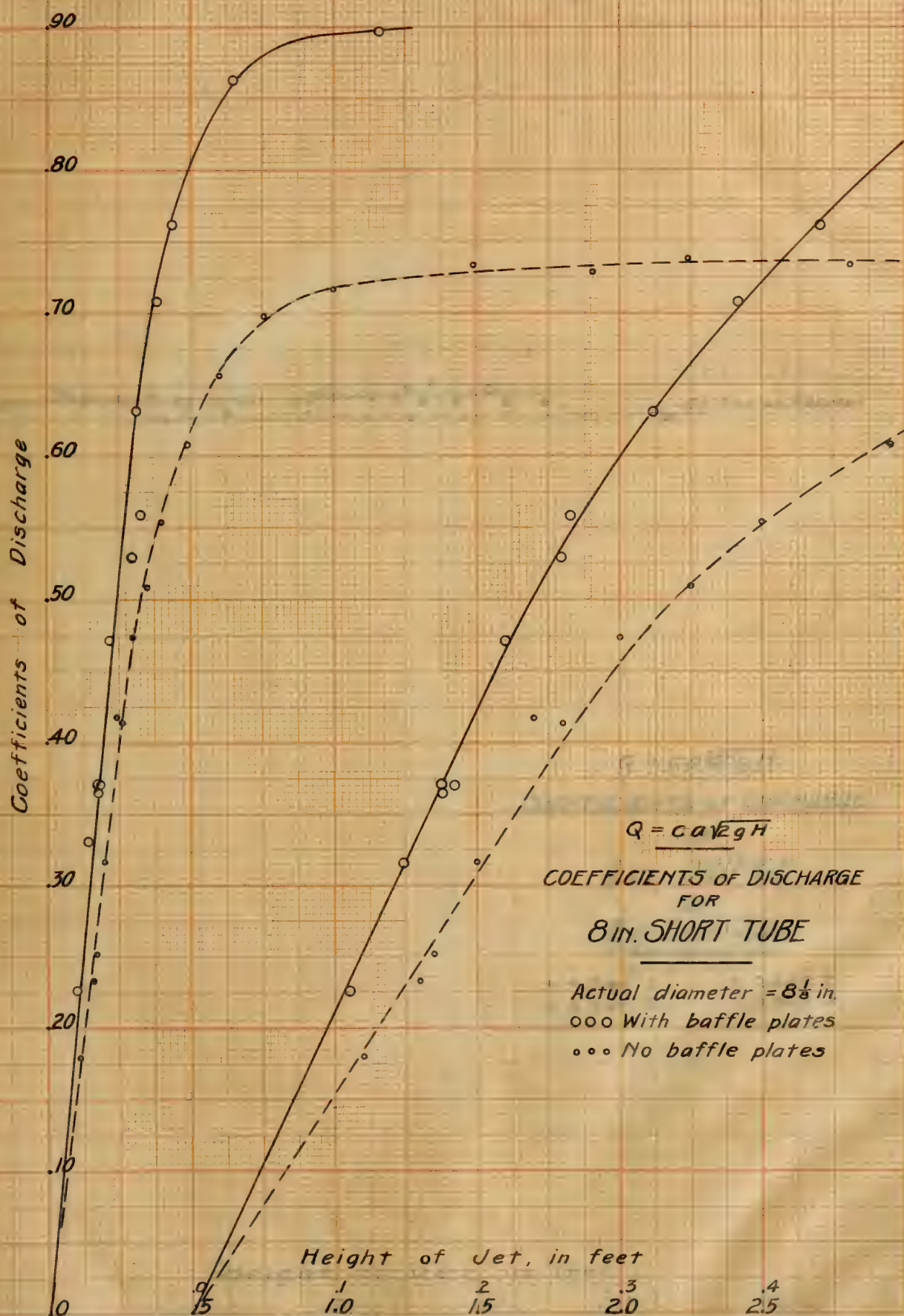
Normal diameter in  
Normal diameter in  
Length in feet

Height of jet in feet

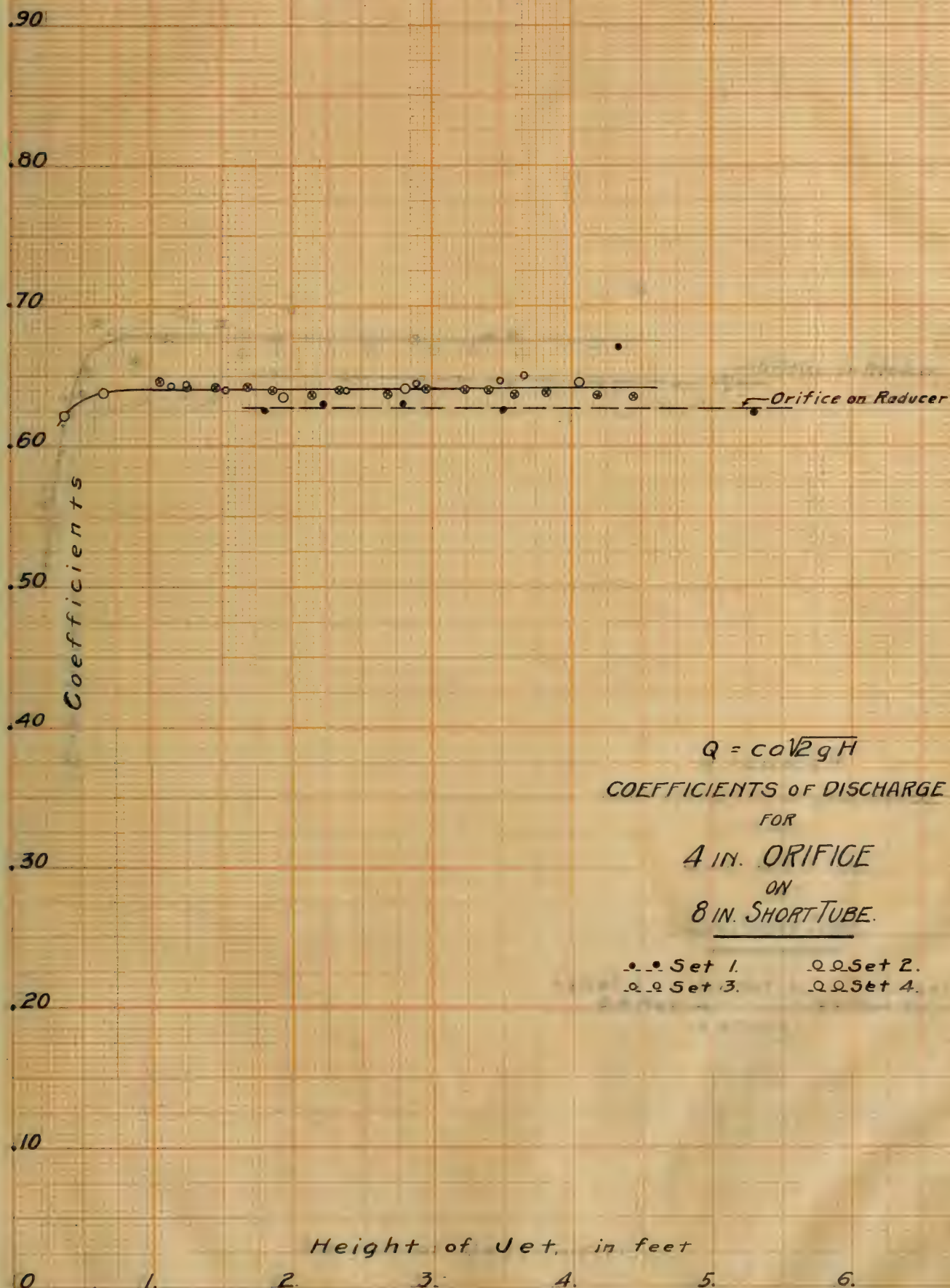
1. 2. 3. 4. 5. 6. 7. 8. 9. 10.

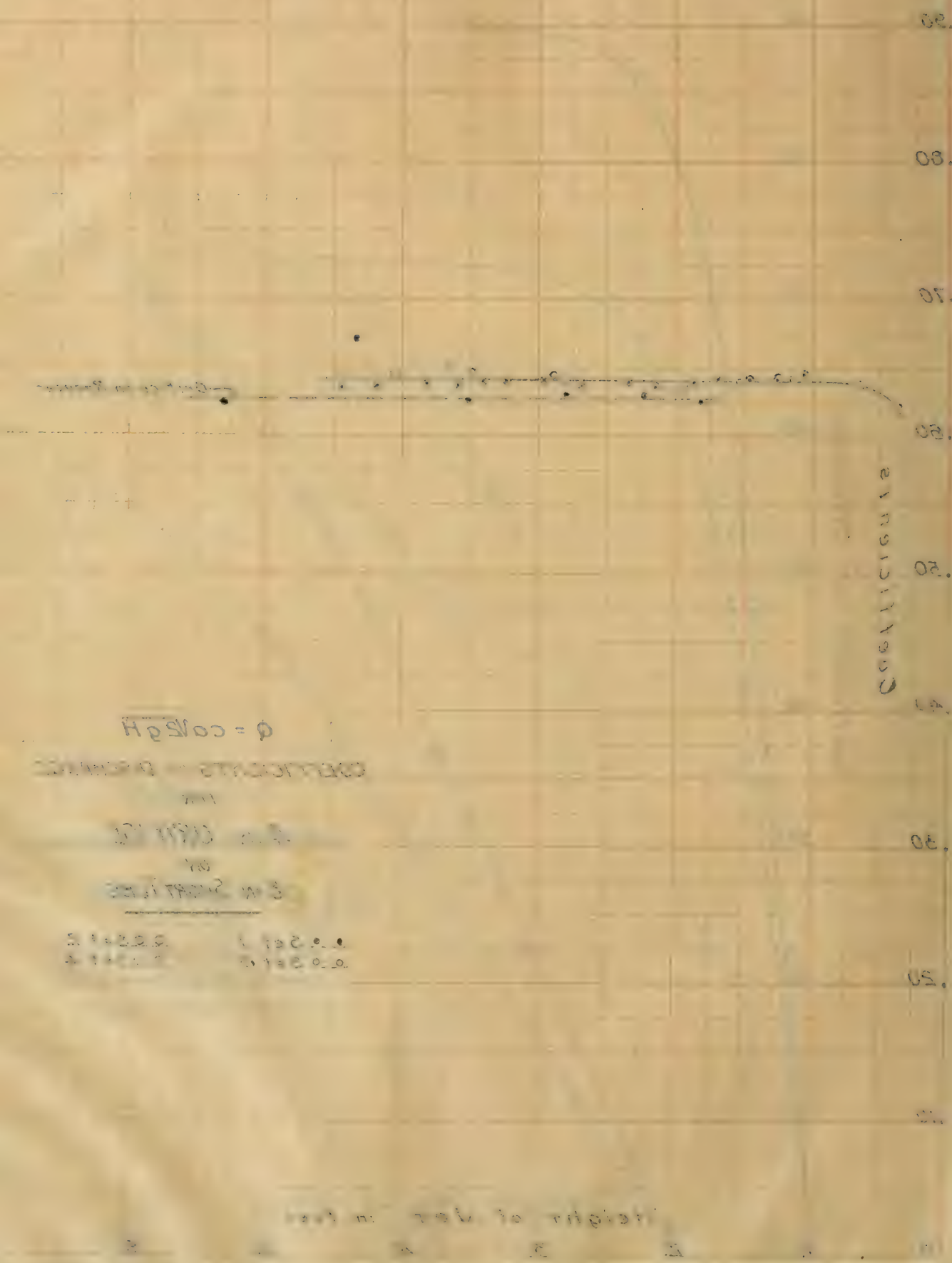
Distance in feet

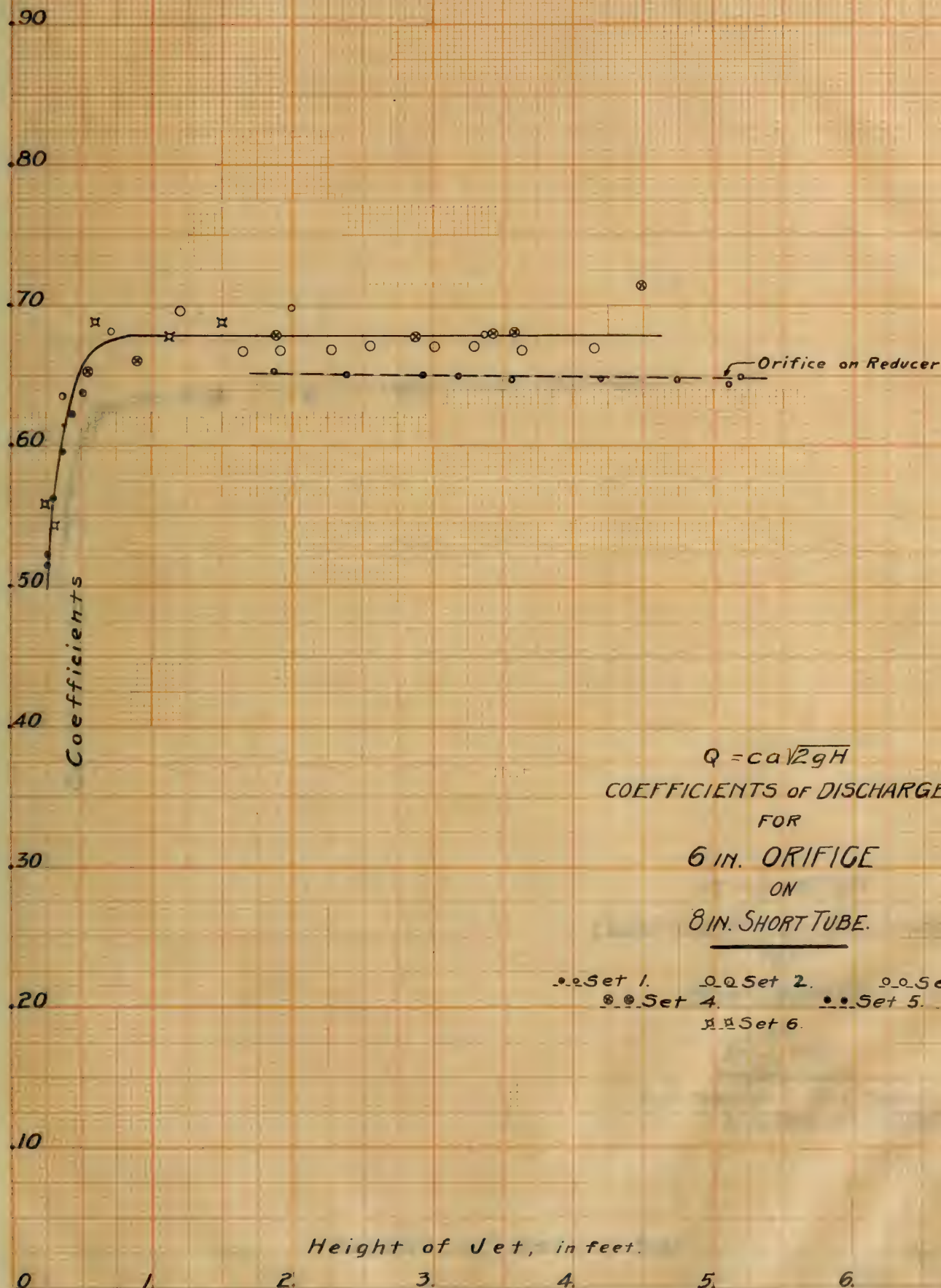
1. 2. 3. 4. 5. 6. 7. 8. 9. 10.





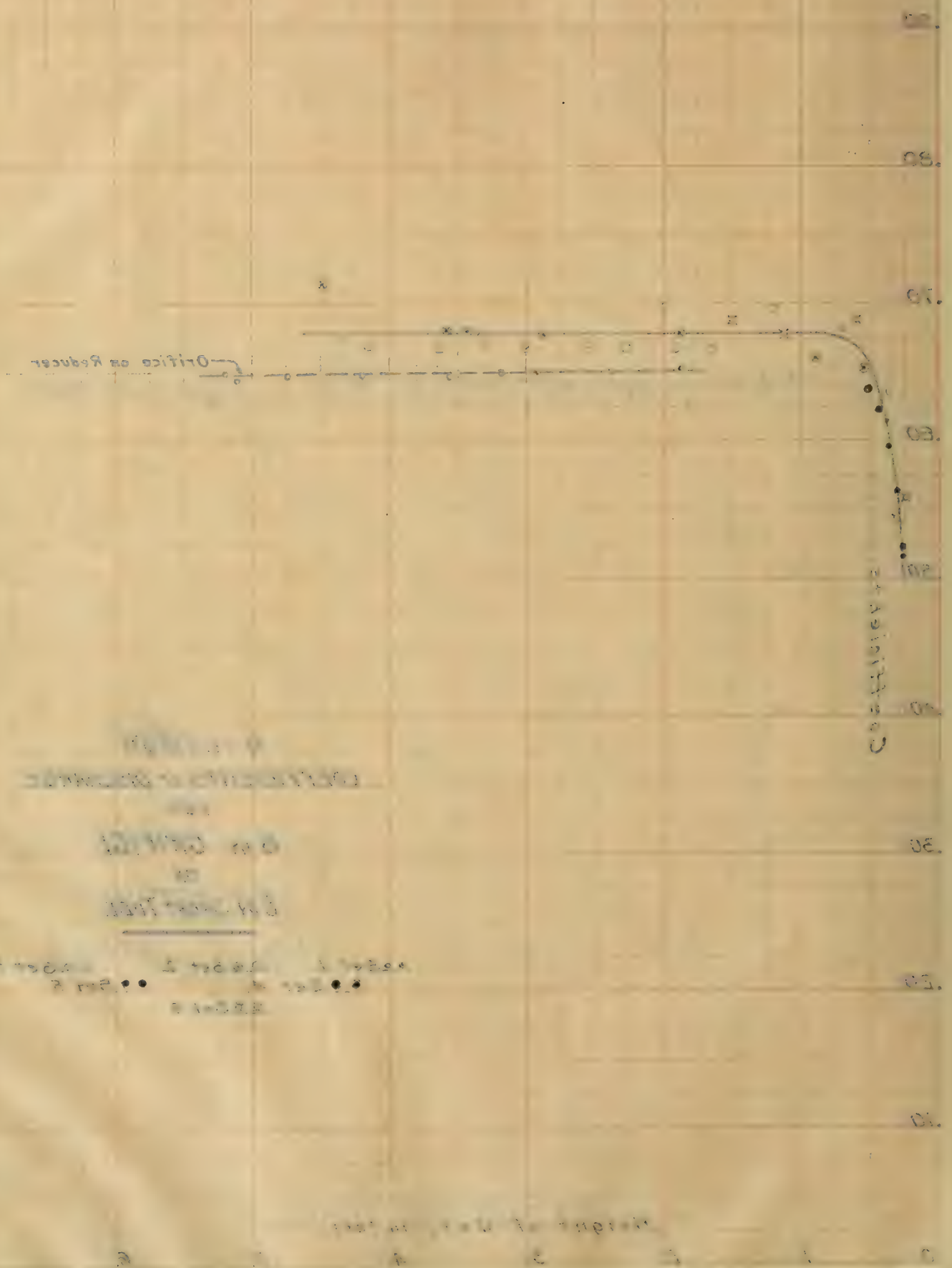






$Q = ca\sqrt{2gH}$   
 COEFFICIENTS OF DISCHARGE  
 FOR  
 6 IN. ORIFICE  
 ON  
 8 IN. SHORT TUBE.

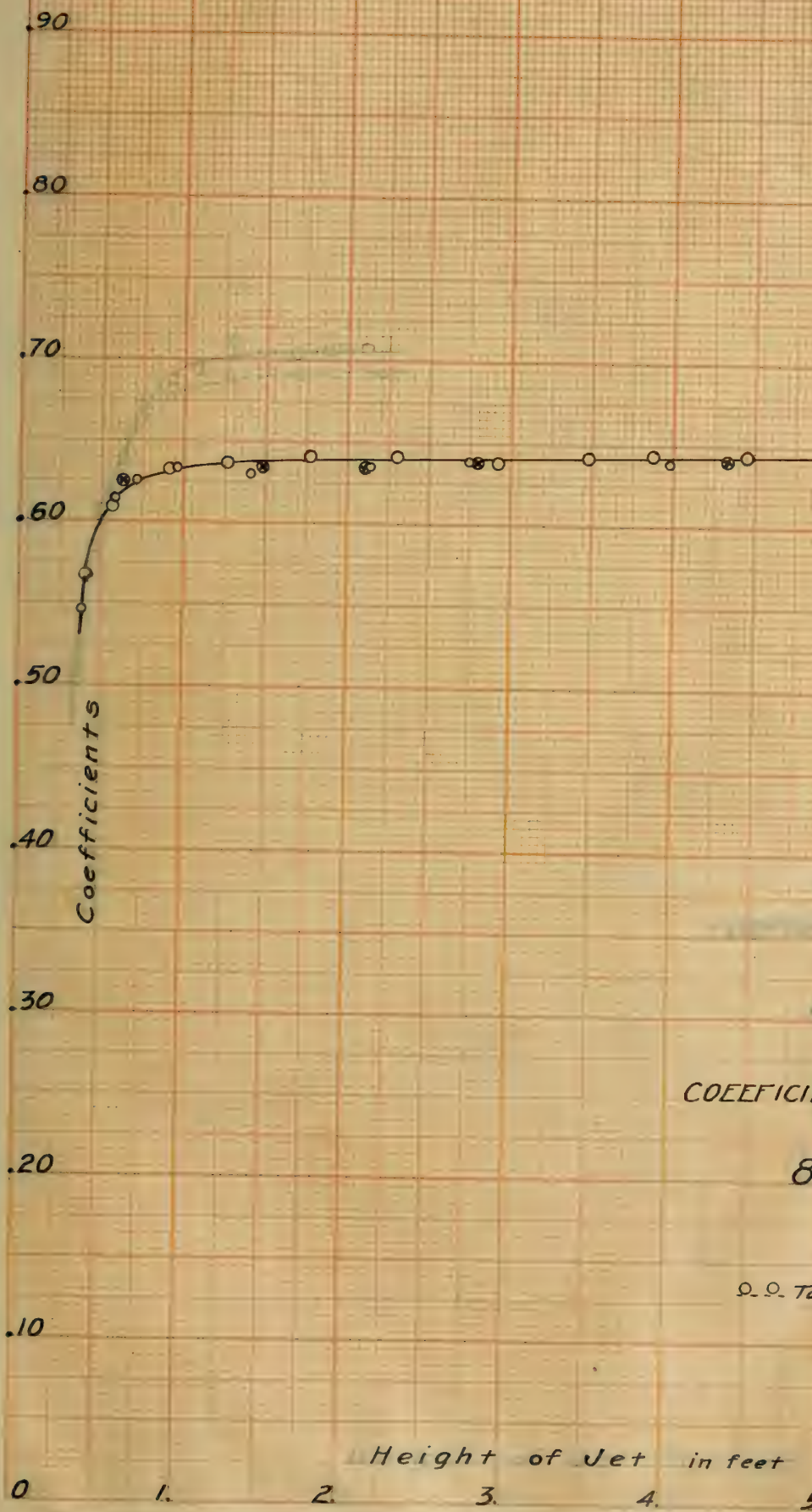
Set 1. Set 2. Set 3.  
 Set 4. Set 5.  
 Set 6.



100%  
 50%  
 0%  
 0.0 0.2 0.4 0.6 0.8 1.0

1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0  
 0.0 0.2 0.4 0.6 0.8 1.0

1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0  
 0.0 0.2 0.4 0.6 0.8 1.0



$$Q = ca\sqrt{2gH}$$

COEFFICIENTS OF DISCHARGE  
FOR

8 IN. ORIFICE

ON

12 IN. PIPE

o-o Table 14

o-o Table 15

o-o Table 13 (1 baffle)

15745-0

CONTENTS OF VOLUME

101

2015 11 15

75 :

[illegible]

1890

.90

.80

.70

.60

.50

.40

.30

.20

.10

Coefficients

Height of Jet in feet

0.

1.

2.

3.

4.

5.

6.

$$Q = ca\sqrt{2gH}$$

COEFFICIENTS OF DISCHARGE  
FOR

10 IN. ORIFICE

ON

12 IN. PIPE

.99.1 baffle only (Table 16)  
.99.2 baffles (Table 17)

02.

03.

07.

08.

09.

STRESS (PSI)

04.

05.

06.

01.

Fig. 10 - 0

COMPARISON OF STRESS

AND

STRAIN

FOR

100% STAIN

Material: 100% STAIN

100% STAIN

100% STAIN

100% STAIN

0

1

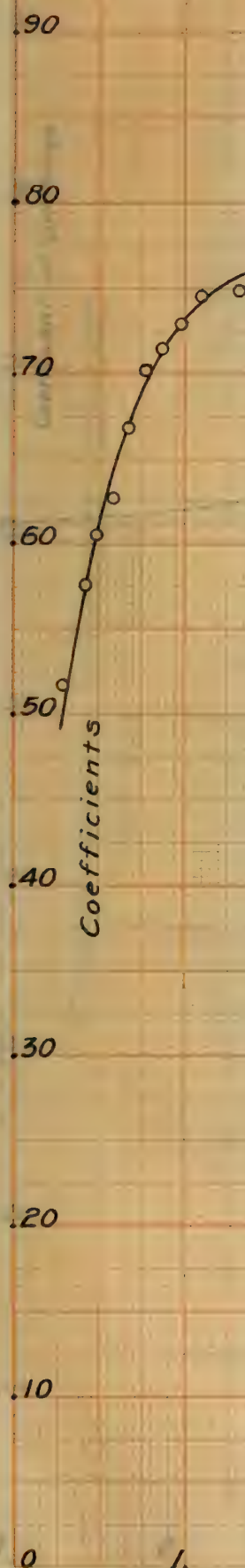
2

3

4

5

6



$$Q = ca\sqrt{2gH}$$

COEFFICIENTS OF DISCHARGE  
FOR

11 IN. ORIFICE

ON

12 IN. PIPE

2 baffles used

Fig. 10

COEFFICIENTS OF EXPANSION

FOR

1000 m. H.

at

1000 m. H.

See text for details

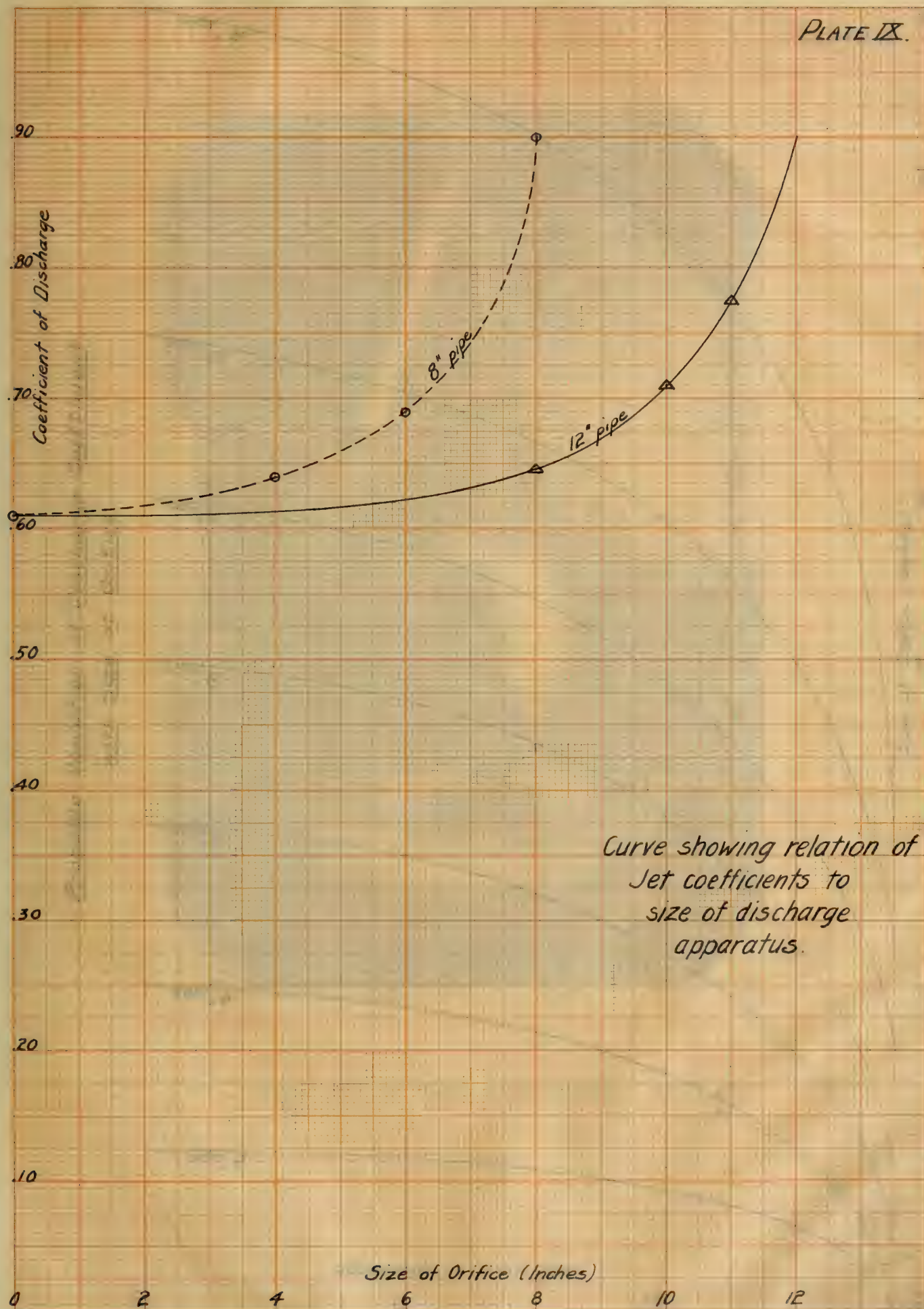
Height of water in feet

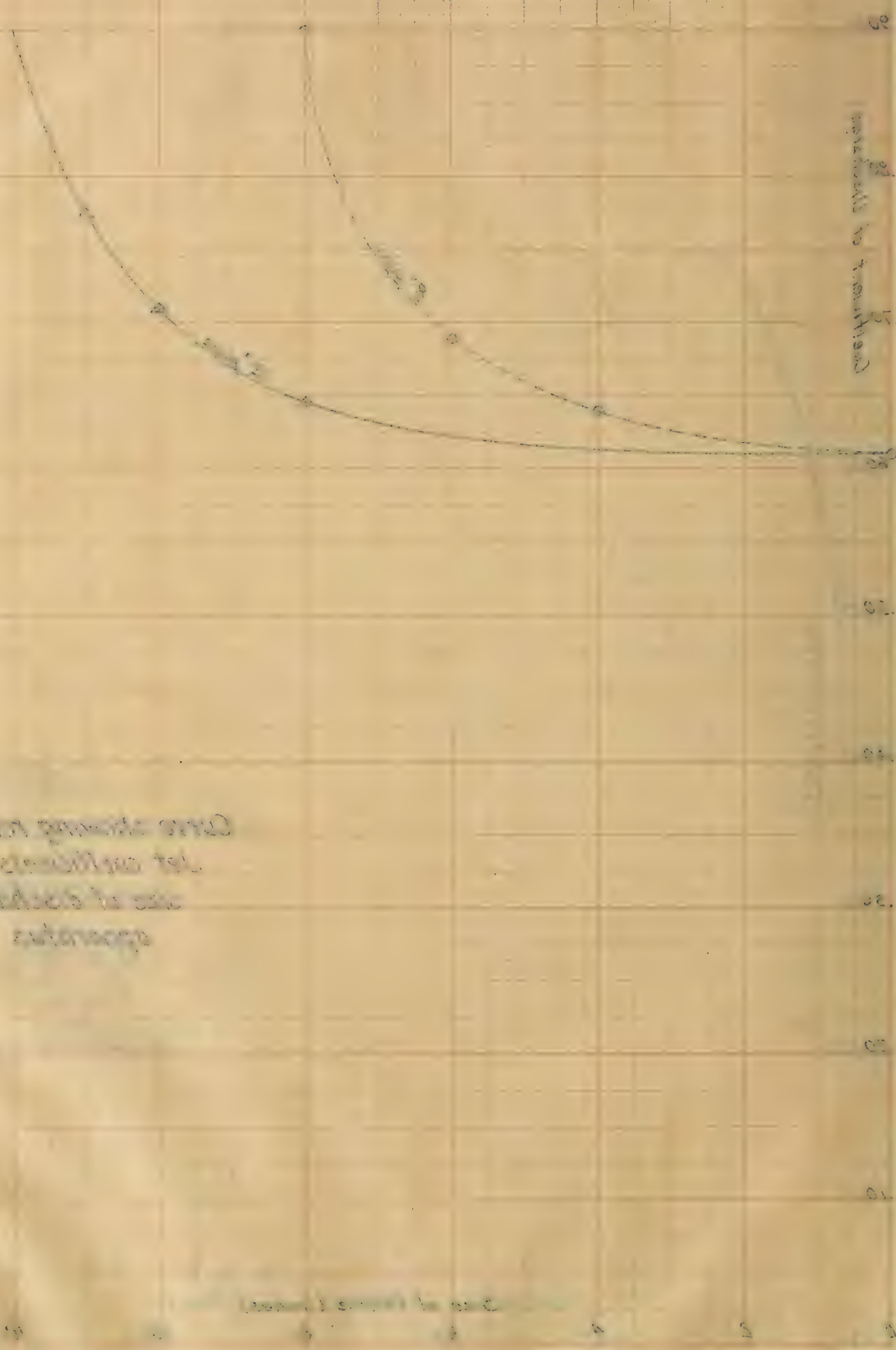
0 1 2 3 4 5 6

Coefficients

0.00  
0.01  
0.02  
0.03  
0.04  
0.05  
0.06  
0.07  
0.08  
0.09  
0.10

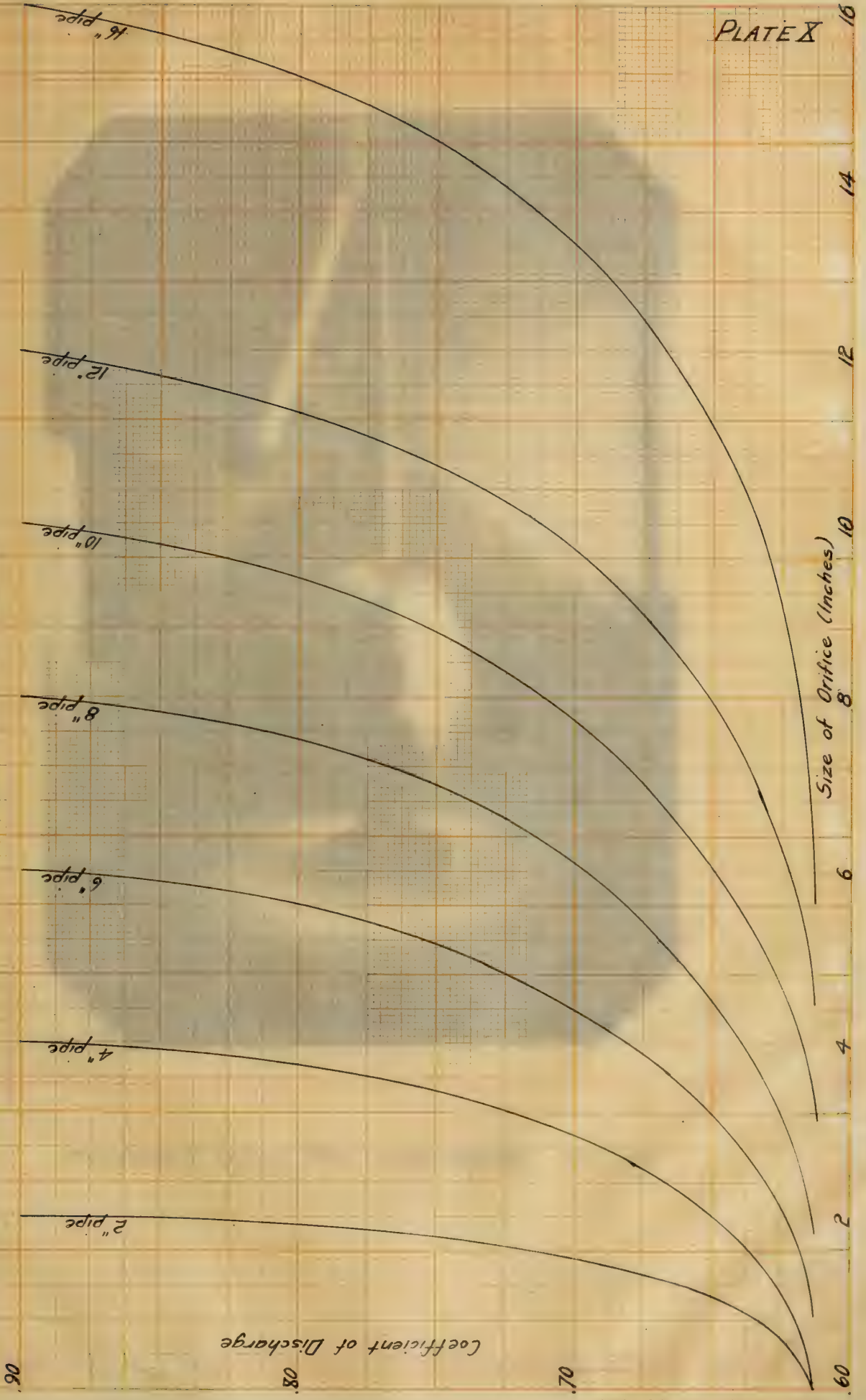




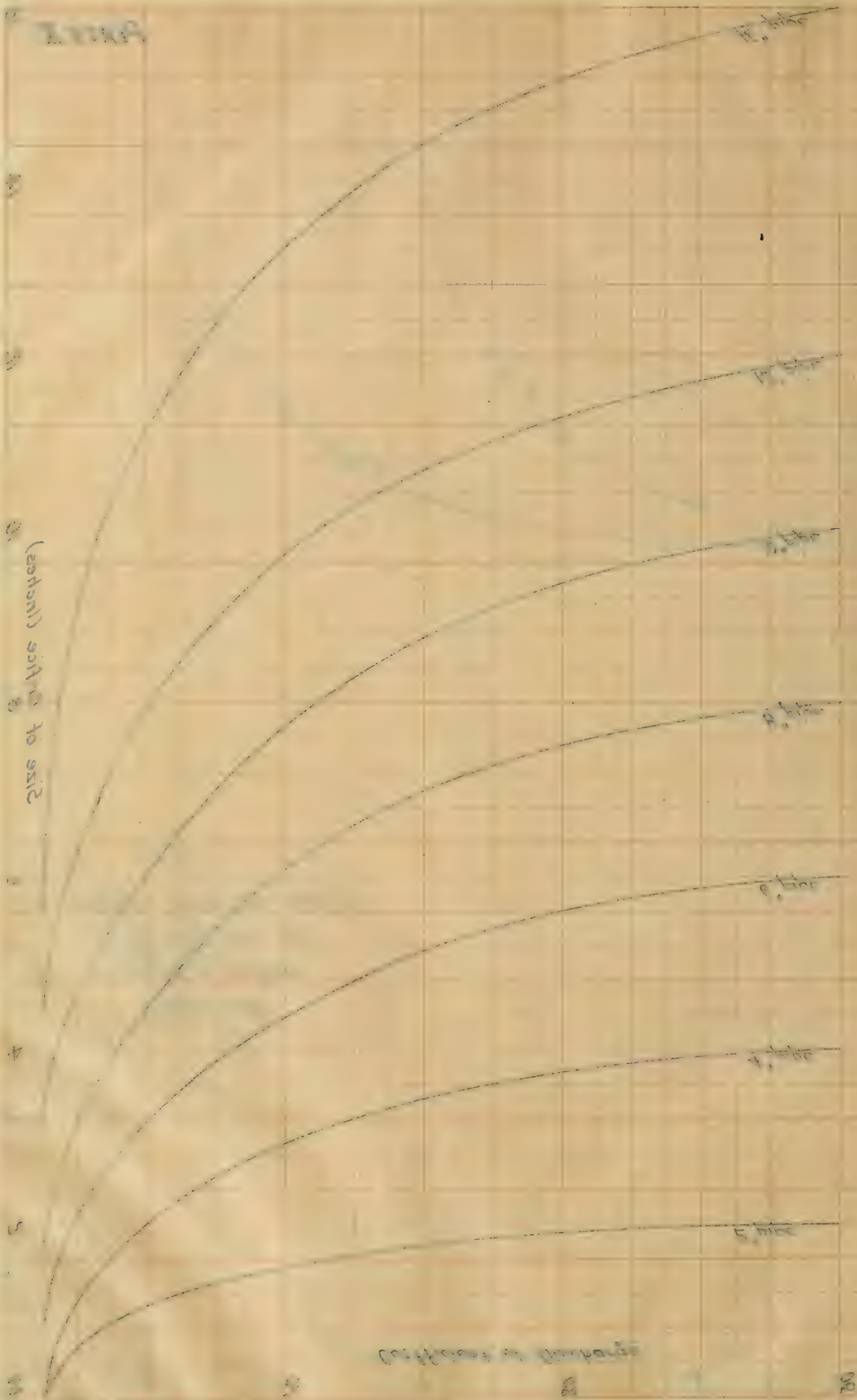


Curve showing relation of log. of t. in hours to log. of t. in hours

Probable Variation of Discharge Coefficient  
with Size of Orifice



INTEGRATED EQUATIONS TO DETERMINE  
RELATIONSHIP OF TEMPERATURE  
AND PRESSURE TO RATE OF  
REACTION





6 IN. ORIFICE ON 8 IN. PIPE DISCHARGING 7 IN. JET





6 in. ORIFICE ON 8 in. PIPE DISCHARGING 2 FT. JET





6 IN. ORIFICE ON 8 IN. PIPE DISCHARGING 4 FT. JET





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